ECOLOGICAL RISK ASSESSMENT OF LANDSCAPE PATTERN EVOLUTION IN YULIN CITY, SHAANXI PROVINCE, CHINA

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Abstract. This study aims to provide a reference for risk management and high-quality development of the land ecosystem in Yulin City. The research selects land use data from five periods between 1985 and 2020 in Yulin City, China, and calculates the landscape pattern index using the Fragstats4.2 platform. An ecological risk assessment model is employed to evaluate the ecological risks associated with the evolution of Yulin's landscape patterns. The study found that although the areas of cultivated land and grassland in Yulin varied over time, these two types of land use remained dominant. Grassland had the largest increase in area, expanding by 6290.98 km², while cultivated land had the largest decrease, reducing by 3562.95 km². The landscape ecological risk index in Yulin exhibited a pattern of "increasing, then decreasing, and increasing again," with an overall upward trend. The area of medium and high-risk zones expanded, while the low-risk zone decreased. The landscape ecological risk in Yulin showed a significant positive correlation and demonstrated spatial clustering. High-risk areas were concentrated in the western, southern, and northern parts of Yulin, while low-risk areas were primarily located in the central region.
Keywords: *land use change, sustainable development, remote sensing, urbanization, spatial analysis*

Introduction

The relationship between land use change and ecological risks has become a central issue in the fields of environmental science, geography, and sustainable development (Wang et al., 2025). As the global population continues to grow and urbanization accelerates, the impacts of land use change on ecosystems have become increasingly significant (Chang et al., 2024). These changes not only alter the type and intensity of land use but also pose serious threats to the stability and diversity of regional and global ecosystems (Zong et al., 2025). In particular, regions with frequent human activities have seen increasing concerns about ecological risks associated with land use change (Anderson et al., 2024). According to the United Nations Environment Programme (UNEP), approximately 40% of the global land area is facing varying degrees of degradation, with land use change being a major driver (Huang et al., 2024). In China, a large and ecologically diverse country (Okembo et al., 2024), land use change has a particularly strong impact on ecological risks (Yuan et al., 2024), especially in the western regions where harsh natural conditions and increasing human activity exacerbate environmental challenges (Wu et al., 2024). Yulin City, located in the northern part of Shaanxi Province and situated on the Loess Plateau, is a typical semi-arid region. In recent years, with the expansion of mining, agriculture, and urbanization,

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the land use pattern in Yulin has undergone drastic changes, significantly affecting the local ecological functions and exacerbating regional ecological risks. In particular, the ecological vulnerability of Yulin and the long-term impacts of land use changes on its environment have become urgent research topics. The ecological risks in Yulin are mainly manifested in soil erosion, vegetation degradation, and loss of biodiversity, which severely threaten the region's sustainable development.

Given this context, in-depth research into the relationship between land use and ecological risks in Yulin City is essential not only to understand the specific mechanisms of land use changes but also to provide scientific evidence for land management, ecological protection, and policy formulation at the local level. As the Chinese government increasingly emphasizes ecological civilization construction, research on land use and ecological risks is moving to the forefront and has achieved significant advancements in practical applications. In particular, with the rapid development of remote sensing technology and Geographic Information System (GIS) techniques, dynamic studies on the impact of land use change on ecological risks have made notable progress.

The relationship between land use and ecological risks has been a hot topic in ecology, geography, and environmental management (Escobar et al., 2024). A large body of literature has explored the impact of land use change on the environment (Ke et al., 2024), enriching the theoretical framework of ecology and providing important references for policy-making and land management. Internationally, research on land use change and ecological risks began earlier and has employed diverse methods (Zhou et al., 2024). For example, the Land Change Model (LCCM) proposed by Zhang and Atkinson (2008) has been widely used to analyze land use changes in different regions, helping researchers understand the relationship between land use change and ecosystem services. Ogoke et al. (2009) further explored the non-linear impacts of land use change on ecological risks, proposing that land use changes can affect ecological risks through multiple pathways, with this impact showing considerable variation across different regions and scales (Wei et al., 2024). In recent years, many scholars have combined remote sensing technology with GIS to propose dynamic land use change models, which have been applied in regional ecological risk assessments (Wang et al., 2024). These methods not only provide spatial distribution characteristics of land use change but also effectively capture the temporal dynamics of land use and ecological risk relationships (Singh et al., 2024).

In China, research on the relationship between land use and ecological risks started later but has gradually deepened as land use management and ecological protection policies have strengthened (Hu et al., 2024). Che et al. (2024) used remote sensing imagery to reveal the spatial characteristics of land use change in the northwest region of China, pointing out the impact mechanisms of land use change on ecological risks. Zhao et al. (2024) constructed a model of land use and ecosystem services relationships and explored the impact of different land use types on ecological risks, revealing that different land use types played varying roles in the accumulation of ecological risks (Gao et al., 2023). In recent years, as China has placed greater emphasis on ecological civilization construction, some scholars have applied ecological risk assessment methods to local land management (Li et al., 2023). For instance, Xu et al. (2023) analyzed the relationship between land use change and ecological risk response in the Loess Plateau region and proposed an ecological risk assessment model based on land use change, providing theoretical support for regional ecological protection (Yuan et al., 2023). However, despite the substantial amount of research on land use and ecological risks, several limitations remain. Most of the studies focus on the static relationship between land use types and environmental quality, neglecting the dynamic characteristics and temporal-spatial impacts of land use change (Xu et al., 2022). Furthermore, existing ecological risk assessment methods are often one-dimensional and lack a comprehensive, multi-dimensional approach to risk evaluation (Cao et al., 2022). Additionally, although policy factors play a crucial role in the relationship between land use change and ecological risks, the existing literature has not fully considered the influence of socio-economic and policy factors on this relationship (Hong et al., 2022).

Despite substantial research on land use and ecological risks, several gaps exist, particularly in the context of specific regions. For Yulin City, a semi-arid region with unique geographical and socio-economic characteristics, further research into the relationship between land use change and ecological risk response is necessary. Firstly, research on the temporal-spatial dynamics of land use change is limited, particularly for regions like Yulin. The long-term trends of land use change and the temporal-spatial responses of different land use types to ecological risks are still unclear. Secondly, ecological risk assessment methods remain predominantly one-dimensional, with a lack of comprehensive, multi-dimensional risk evaluation frameworks. Existing studies have mainly focused on individual ecological risk factors, neglecting a systematic analysis of the multiple dimensions of ecological risk impacts. Additionally, while policy factors are known to affect land use change and ecological risks, the role of social and economic factors in the relationship between land use and ecological risk remains underexplored. Therefore, by conducting an ecological risk assessment of the evolution of landscape patterns, exploring the mechanisms influencing landscape pattern generation and regulation can provide a theoretical foundation for the high-quality use of land resources in ecologically fragile areas. This study selects Yulin City, China, as the research subject and examines the close relationship between landscape layout and land use. By constructing an evaluation model, the ecological risk of land use landscapes in Yulin City is comprehensively assessed, providing research support for the high-quality development of ecologically vulnerable areas.

Materials and methods

Study area

Yulin City (36°57′~39°35′N, 107°15′~111°15′E) is located in the northernmost part of Shaanxi Province, China, bordering Yan’an City and adjacent to provinces and autonomous regions such as Ningxia, Gansu, and Inner Mongolia (*Fig. 1*). The terrain features a northwest-high, southeast-low pattern. Yulin is situated in the transitional zone between the Maowusu Desert and the Loess Plateau. The southern flat areas are mainly composed of the Ordos Plateau and Loess Hill and Gully Region. With fragile natural ecology, the city’s topography can be divided into sand dune areas and loess hill and gully areas. The soil types are primarily dryland soils developed from loess parent material, with loess ridges and gully lands as the main landforms. Based on soil texture and profile morphology, the soils can be categorized into fine sandy loess, sandy loam, black loess soil, gray calcareous soil, white ash soil, gray-brown soil, and yellow soft soil. There are three main types of vegetation: first, forest vegetation, mainly distributed in Yuyang District, Shenmu County, Hengshan District, and Zizhou County; second, grassland

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vegetation, mainly distributed in Fugu County, Mizhi County, Qingjian County, and the southern parts of Qingjian and Wubu Counties; third, desert vegetation, mainly distributed in the southern edge of the Maowusu Desert in the northwest of Yulin City. The main soil types present in the study area, including fine sandy loess, sandy loam, black loess soil, gray calcareous soil, white ash soil, gray-brown soil, and yellow soft soil.

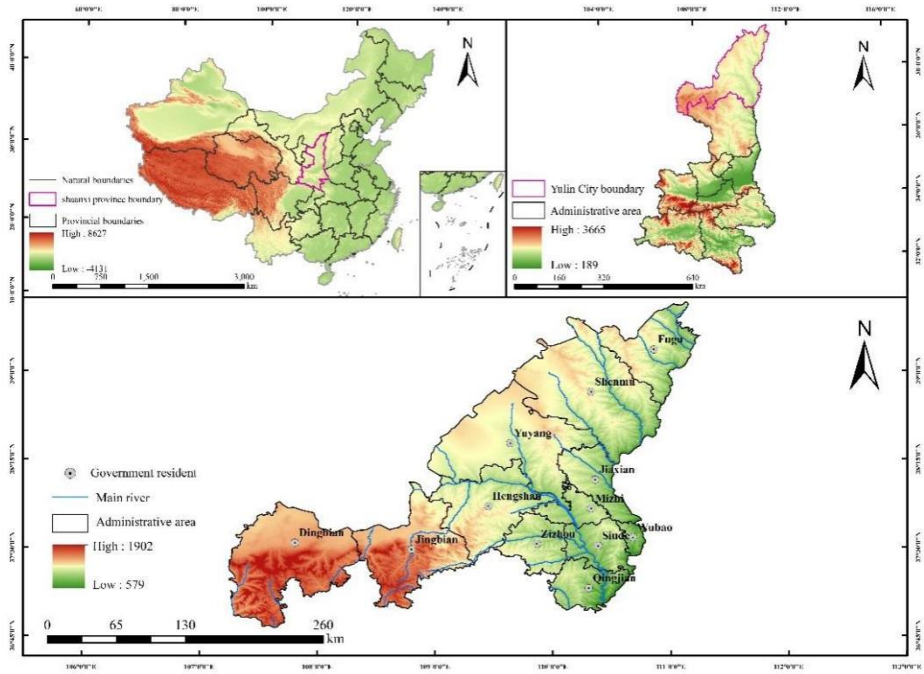

Figure 1. *Maps displaying the location of the Yulin in China*

Data sources

The remote sensing data for land use in Yulin City from 1985 to 2020, covering five periods, was provided by the Geospatial Data Cloud of the Chinese Academy of Sciences' Resources and Environment Science and Data Center (https://www.resdc.cn). The study classified land use into six major types: cultivated land, forest land, grassland, water bodies, built-up land, and unused land. To investigate the spatial distribution characteristics of ecological risk indicators, the study employed an equidistant sampling method, dividing Yulin City into 1920 independent grid units. The risk values calculated by the model were input into the core locations of risk zones, followed by Kriging interpolation. Landscape indices were then calculated for each grid, and finally, the Fragstats 4.2 software was used to compute the landscape ecological risk index for each grid. The satellite images, provided by the Geospatial Data Cloud of the Chinese Academy of Sciences, have a resolution of 30 meters, which was maintained throughout the image processing procedures.

Research methodology

Construction of ecological risk assessment model

Using landscape ecology theory, indicators reflecting regional spatial ecological risks were selected. By calculating indices such as landscape disturbance, vulnerability, and

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loss for ecological risk units, an ecological risk assessment model was constructed to evaluate the changing characteristics of ecological risk in Yulin City.

(1) Calculation of landscape pattern indices

Landscape indices condense information about landscape patterns, revealing the composition of landscape structure and reflecting the impact of human activities on landscape patterns (Li et al., 2022). Landscape pattern indices for various periods from 1985 to 2020 in Yulin City were selected (*Table 1*), and the Fragstats 4.2 software was used to calculate the landscape pattern indices for Yulin City from 1985 to 2020.

(2) Construction of the landscape ecological risk index

(a) Ecological risk unit division. Based on the urban area size of Yulin City and the average size of landscape patches, the area was divided into a grid of 5 km × 5 km using equidistant sampling, resulting in a total of 1920 risk units. On this basis, an ecological risk model and landscape ecological risk index were constructed, using the landscape ecological risk index as the evaluation indicator to assess the ecological risk at each sample point (Li et al., 2022).

(b) Landscape disturbance index (Ci). This index represents the degree to which different landscape types are affected by external factors. It is calculated using the landscape fragmentation index, landscape separation index, and landscape dominance index (He et al., 2022). Its expression is as follows:

$$C_i = aD_i + bF_i + cE_i \quad \text{(Eq.1)}$$

$$D_i = \frac{n_i}{S_{ji}} \quad \text{(Eq.2)}$$

$$F_i = \frac{S_j}{2S_{ji}}\sqrt{\frac{n_i}{S_j}} \quad \text{(Eq.3)}$$

$$E_i = \frac{H_i + L_i}{4} + \frac{M_i}{2} \quad \text{(Eq.4)}$$

In the formula, D_i represents the landscape fragmentation index, n_i is the number of patches of landscape type, S_{ij} is the area of landscape type, S_j is the total area of all landscapes, F_i is the landscape separation index, E_i is the landscape dominance index, H_i is the ratio of the number of sample plots where the landscape type appears to the total number of sample plots, L_i is the ratio of the number of patches of landscape type to the total number of patches, M_i is the ratio of the patch area of landscape type to the total sample plot area. The values of a, b, and c are the weights, and according to a large number of related studies, a, b, and c are assigned values of 0.5, 0.3, and 0.2, respectively.

(c) Landscape vulnerability index (K_i). K_i refers to the degree of vulnerability of the landscape to external disturbances. After assigning values to the vulnerability of each landscape type, normalization is performed (Lechner and Kirisits, 2022).

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(d) Landscape loss index (P_i). P_i is calculated by multiplying the disturbance and vulnerability of each landscape, and the calculation formula is as follows (Getachew and Manjunatha, 2022):

(e) Ecological risk assessment model (ERI). The establishment of the landscape ecological risk index is based on the degree of external disturbance to the regional ecosystem and its internal resistance capacity. When the external disturbance to the regional system is more severe, its resistance to external disturbances is weaker, leading to an increase in ecological risk. Conversely, the risk decreases (Xu et al., 2022). The expression is as follows:

$$ERI = \sum_{i=1}^{n} \frac{S_{ji}}{S_j} \times P_i \qquad \text{(Eq.5)}$$

ERI is the ecological risk index, n is the number of landscape types within the ecological risk unit, S_{ji} is the area of the j-th type of ecological risk unit, and S_j is the total landscape area.

Results

Land use change analysis

As shown in *Figure 2*, between 1985 and 2020, although the area of cultivated land and grassland in Yulin City fluctuated, they remained the two dominant land use types. Grassland had the largest increase in area, expanding by 6290.98 km^2. The grassland areas in 1985, 1990, 2000, 2010, and 2020 were 26,809.99 km^2, 27,364.70 km^2, 28,259.96 km^2, 30,447.07 km^2, and 33,100.97 km^2, respectively. The proportion of grassland area to the total basin area exceeded half in each period, with values of 62.57%, 63.87%, 65.96%, 72.20%, and 77.26%. The area of built-up land increased next, from 157.57 km^2 in 1985 to 543.49 km^2 in 2020, with the proportion decreasing from 28.86% to 20.54% by 2020. The area of cultivated land decreased from 12,363.72 km^2 in 1985 to 8,800.77 km^2 in 2020, representing the largest decrease among all land types. The area of unused land decreased from 831.58 km^2 in 1985 to 195.91 km^2 in 2020, with its proportion dropping from 7.81% in 1985 to 0.42% in 2020 (*Table 1*).

From 1985 to 2020, cultivated land in Yulin City was primarily distributed in the southern counties, such as Zizhou County, Qingjian County, Jingbian County, and Dingyuan County. In contrast, areas near the northern desert regions had relatively less cultivated land. Overall, the area of cultivated land in Yulin City showed a decreasing trend (*Fig. 2*). Grassland was mainly distributed in the northern regions, such as Fugu County, Shenmu City, Yuyang District, and Jiaxian County, while areas near the southern regions had less grassland. From 1985 to 2010, the area of grassland in Yulin City continuously expanded into the southeastern regions, with to significant results in desert reclamation. From 2010 to 2020, the grassland from cultivated land, indicating the significant effect of the “returning farmland to grassland” policy. Forest land was mainly concentrated in the southern part of Yulin City. From 1980 to 2000, the forest area in the southeastern region slightly increased, which was related to the increase in precipitation in Yulin, sufficient area expanded further into the southwestern regions, with much of the newly added grassland area converted rt tree growth. From 2000 to 2020, the forest area in the southwestern part of Yulin City increased, with most of the new forest land converted from cultivated land, further demonstrating the success of the

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"returning farmland to grassland" policy. From 1985 to 2020, the area of built-up land in Yulin City steadily increased, mainly distributed along the Wuding River Basin. These areas were primarily productive cultivated lands, and the change was largely driven by the rapid population growth and socioeconomic development in Yulin City, leading to a sharp increase in built-up land.

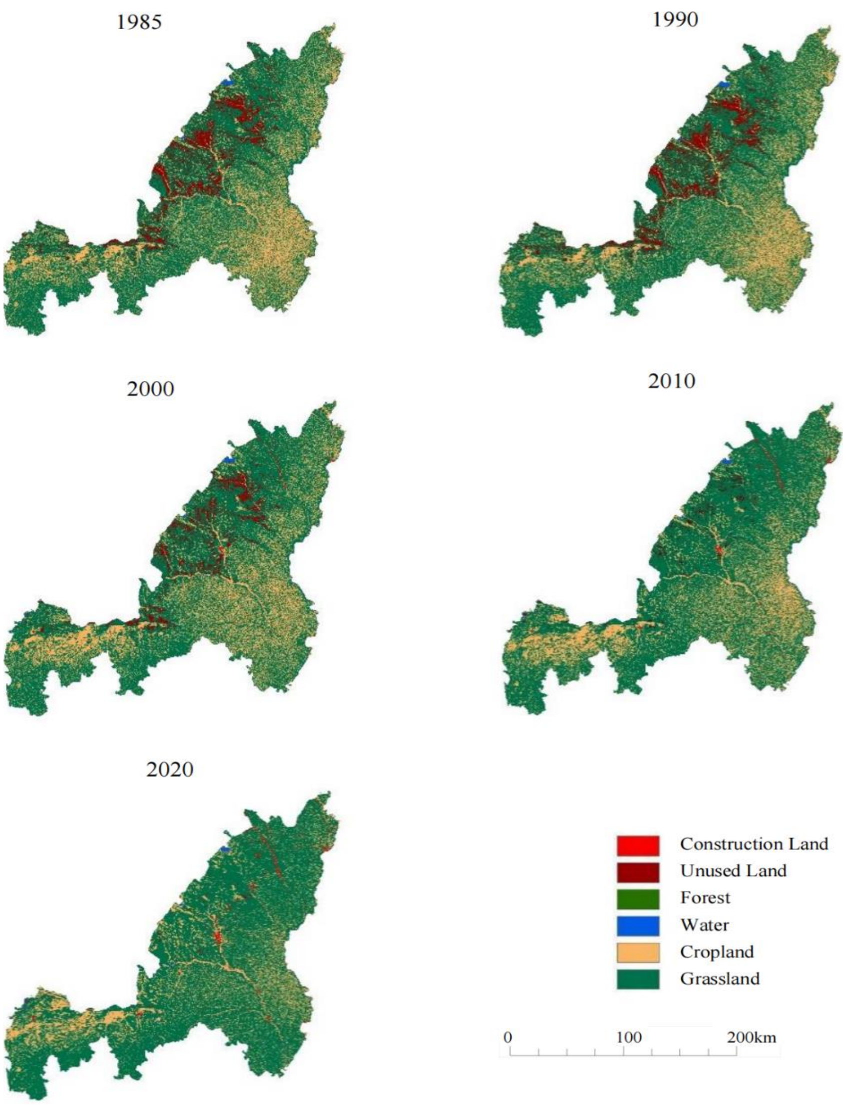

Figure 2. *Land use distribution map of Yulin City*

Table 1. *Area and proportion of different types of land use in Yulin City from 1985 to 2020*

Land cover types	1985		1990		2000		2010		2020	
	Area km^2	Proportion %	Area km^2	Proportion %	Area km^2	Proportion %	Area km^2	Proportion %	Area km^2	Proportion %
Cropland	12363.72	28.86	11590.51	27.05	11881.47	27.73	11119.68	26.37	8800.77	20.54
Forest	11.27	0.03	11.18	0.03	10.25	0.02	13.50	0.03	56.11	0.13
Grassland	26809.99	62.57	27364.70	63.87	28259.96	65.96	30447.07	72.20	33100.97	77.26
Water	154.37	0.36	153.69	0.36	164.34	0.38	153.93	0.37	162.56	0.38
Construction land	157.57	0.37	158.43	0.37	241.93	0.56	437.20	1.04	543.49	1.27
Unused land	3348.26	7.81	3566.68	8.32	2287.24	5.34	673.80	1.60	181.29	0.42

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Changes in landscape ecological risk

Based on the attribute values of the ecological risk assessment unit (ERI), the spatial distribution map of ecological risk landscapes in Yulin City from 1985 to 2020 was obtained. From *Figure 3* and *Table 2*, it can be seen that between 1985 and 2020, the landscape ecological risk index in Yulin City showed a "first increase, then decrease, and then increase again" pattern. Overall, the landscape ecological risk index increased, with the areas of medium and high-risk zones expanding, while the areas of low-risk zones decreased. Between 1985 and 1990, the areas of low and relatively low landscape ecological risk zones decreased. The proportion of low-risk areas dropped from 58% in 1985 to 29% in 1990, and the proportion of relatively low-risk areas decreased from 30% in 1985 to 18% in 1990. In contrast, the areas of high, relatively high, and medium-risk zones increased. The proportion of high-risk areas increased from 2% in 1985 to 17% in 1990, while the proportion of relatively high-risk areas rose from 2% in 1985 to 16% in 1990, and the proportion of medium-risk areas increased from 8% in 1985 to 20% in 1990. Between 1990 and 2000, the areas of high, relatively high, and medium landscape ecological risk zones showed a downward trend. The proportion of high-risk areas dropped from 17% in 1990 to 1% in 2000, the proportion of relatively high-risk areas decreased from 16% in 1990 to 3% in 2000, and the proportion of medium-risk areas declined from 20% in 1990 to 10% in 2000. Meanwhile, the areas of relatively low and low-risk zones increased. The proportion of relatively low-risk areas rose from 18% in 1990 to 28% in 2000, and the proportion of low-risk areas increased from 29% in 1990 to 58% in 2020, indicating significant ecological protection results. Between 2000 and 2010, the areas of high, relatively high, medium, and relatively low landscape ecological risk zones increased. The proportion of high-risk areas increased from 1% in 2000 to 6% in 2010, the proportion of relatively high-risk areas grew from 3% in 2000 to 10% in 2010, and the proportion of medium-risk areas rose from 10% in 2000 to 19% in 2010. However, the areas of relatively low and low-risk zones decreased. The areas of relatively low-risk zones increased due to growing human activity interference, particularly as the energy and chemical production scale expanded, which intensified the ecological risk in Yulin City. Between 2010 and 2020, the areas of high ecological risk zones showed no significant change, but spatially, the high-risk areas shifted from the northern part of Yulin City to the southern region.

Spatial autocorrelation analysis of landscape ecological risk

Global autocorrelation analysis

Through global autocorrelation analysis of Yulin City for 1985, 1990, 2000, 2010, and 2020, the Moran's I values were found to be 0.846, 0.849, 0.828, 0.734, and 0.829, respectively (*Fig. 4*). These values exhibit a trend of first decreasing and then increasing, indicating that the spatial aggregation of landscape ecological risk in Yulin City weakened initially and then strengthened over time. The Moran's I value was highest in 1990 at 0.849, after which the spatial autocorrelation decreased, reaching the lowest value of 0.734 in 2010. However, after 2010, spatial autocorrelation began to rise again, reaching 0.829 by 2020. In areas with higher landscape ecological risk values, the surrounding regions experienced lower values of other landscape ecological risk levels. Conversely, in areas with lower landscape ecological risk values, the surrounding areas had higher values.

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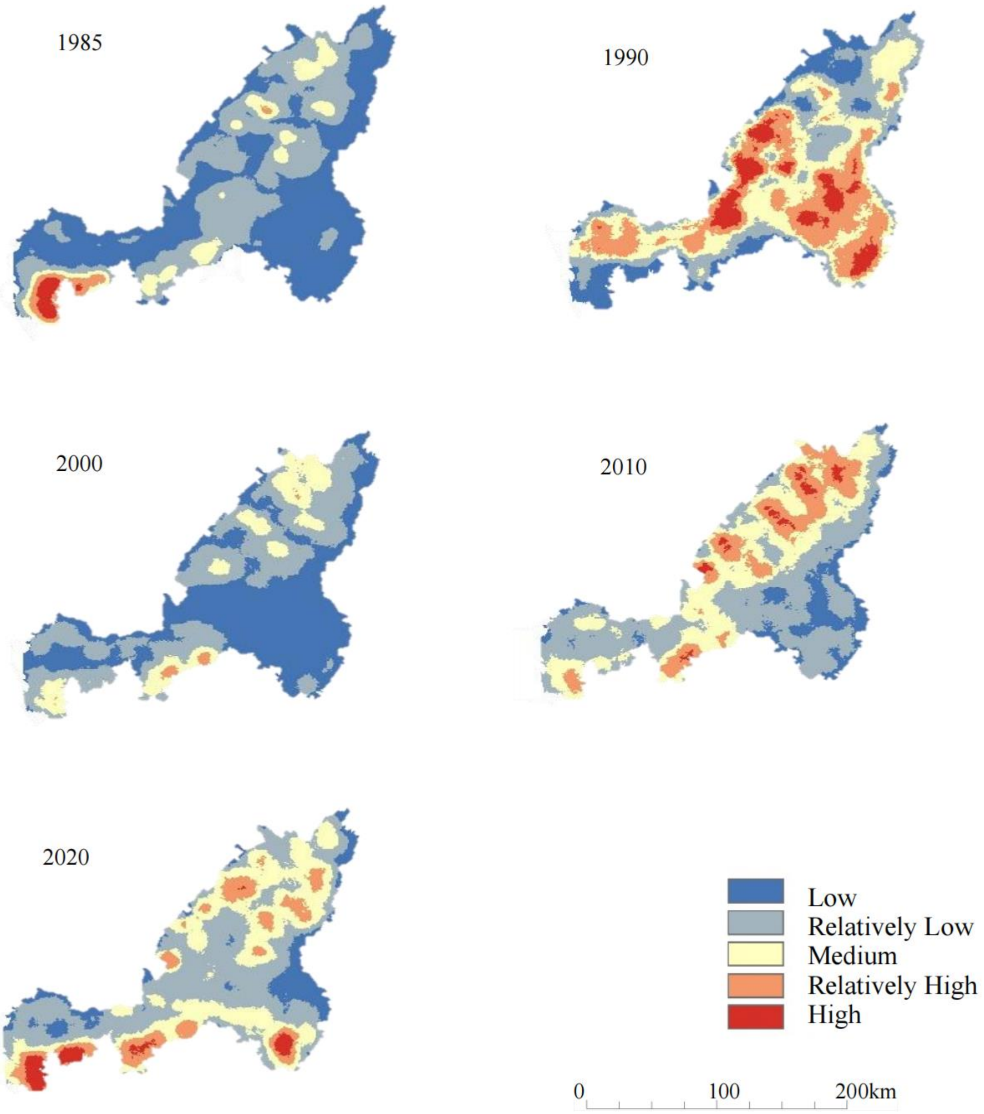

Figure 3. *Spatial-temporal differences in landscape ecological risks in Yulin City from 1985 to 2020*

Table 2. *Area ratio of each ecological risk level in Yulin City*

Year	1 Level area	2 Level area	3 Level area	4 Level area	5 Level area
1985	0.58	0.30	0.08	0.02	0.02
1990	0.29	0.18	0.20	0.16	0.17
2000	0.58	0.28	0.10	0.03	0.01
2010	0.30	0.35	0.19	0.10	0.06
2020	0.30	0.33	0.21	0.11	0.06

Local autocorrelation analysis

From *Figure 5*, it can be observed that between 1985 and 2020, high-high value areas in Yulin City were primarily concentrated in the western, southern, and northern regions. These areas, which underwent extensive coal mining and industrial park construction, led to a trend of landscape loss expanding from the central region to the

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north and south. These areas pursued development by over-exploiting forest land, occupying grassland and cultivated land, especially as the local population grew beyond the land’s carrying capacity. This resulted in low landscape integration, higher fragmentation, and a higher degree of landscape loss. Due to rapid economic development and the increase in industrial parks, the area of built-up land in these regions grew from 157.57 km² in 1985 to 543.49 km² in 2020. Among all land use types, built-up land experienced the highest growth rate, indicating that the population increase necessitated rapid expansion of built-up land, reflecting a rising trend in urbanization. Low-low value areas, on the other hand, were concentrated in the central region. In these areas, efforts to prevent soil erosion and desertification through artificial planting of forests and grass were successful. Unused land was largely covered with forests and grass, resulting in significant human-driven changes in land use, leading to an improvement in the regional ecological environment and preventing land degradation.

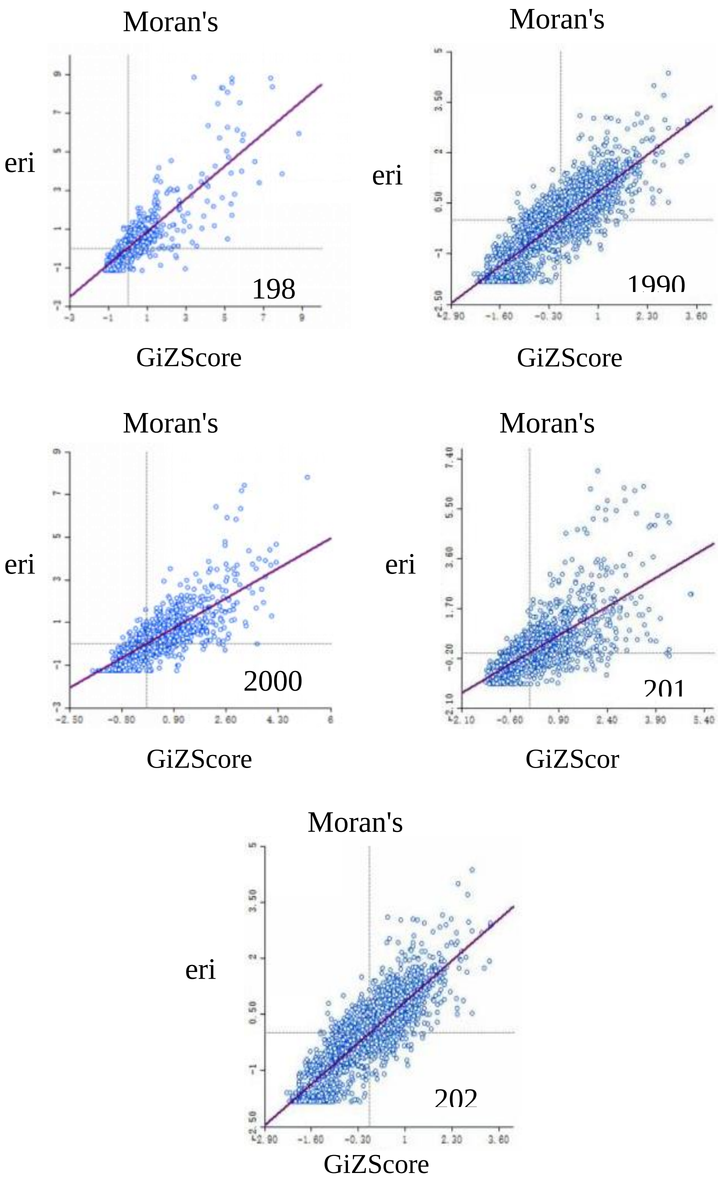

***Figure 4.** Scatter plot of landscape ecological risk in Yulin City*

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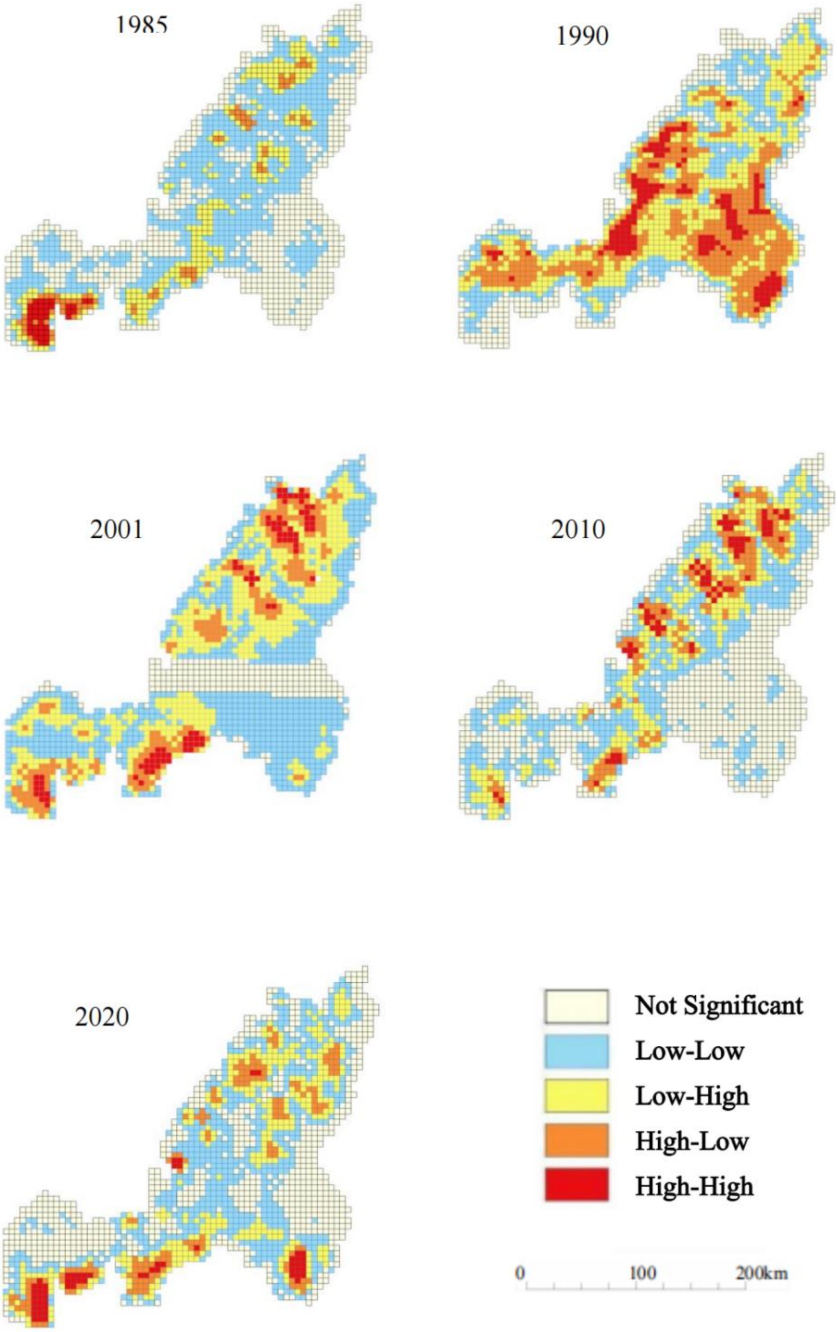

Figure 5. *Local autocorrelation agglomeration of landscape ecological risks in five periods in Yulin City*

Discussion

Land use change analysis

Land use change is a critical aspect of regional environmental sustainability, particularly in ecologically fragile areas such as Yulin City. Over the past few decades, this region has undergone significant land use transformations driven by natural factors and human activities. Our study revealed that between 1985 and 2020, Yulin City experienced substantial shifts in land use types, with notable increases in grassland and

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built-up land at the expense of cultivated land and unused land. Specifically, the area of grassland expanded by 6290.98 km², growing from 26,809.99 km² in 1985 to 33,100.97 km² in 2020, accounting for more than 77% of the total basin area. In contrast, cultivated land decreased significantly, from 12,363.72 km² in 1985 to 8,800.77 km² in 2020, highlighting the impact of land conversion policies such as the “Grain for Green” program.

The spatial pattern of these changes is equally important. Cultivated land was primarily located in the southern counties, while grassland expansion occurred mainly in the northern and southeastern regions. The built-up land increased substantially from 157.57 km² in 1985 to 543.49 km² in 2020, primarily along the Wuding River Basin, reflecting rapid urbanization and economic development. Notably, the conversion of cultivated land to forest and grassland intensified after 2000, demonstrating the success of national ecological restoration policies.

Our findings align with previous studies on land use changes in semi-arid regions of China, which have also documented extensive grassland expansion and a decline in cultivated land due to policy-driven ecological restoration efforts. For example, studies on the Loess Plateau confirm that afforestation and grassland expansion programs have significantly altered land use patterns, enhancing regional ecological functions (e.g., Liu et al., 2019; Wang et al., 2021). However, our study provides a more refined spatial analysis, showing that grassland expansion was initially concentrated in southeastern regions before expanding southwestward, a pattern not previously detailed in other studies.

The factors influencing the landscape changes of land use in the study area include the following: Climate Change: Variations in temperature and precipitation patterns, which affect vegetation growth, soil moisture, and water availability. For instance, prolonged droughts in semi-arid regions like Yulin City lead to the degradation of grassland and forest ecosystems, while heavy rainfall can cause soil erosion and flood-related landscape changes.

Human Activities: Urbanization, agriculture, and industrial development are major drivers of landscape transformation. For example, the conversion of agricultural land to urban areas has led to the fragmentation of habitats, while the expansion of mining operations alters soil structure and vegetation cover.

Land Management Policies: Government policies such as reforestation programs, land reclamation, and the “Grain for Green” program significantly impact landscape types. These policies can lead to the restoration of forest or grassland areas, as well as changes in the distribution of agricultural land.

Natural Disasters: Events such as wildfires, landslides, and floods can dramatically alter landscape types. For example, wildfires in forested areas can lead to the loss of vegetation and the transformation of forest ecosystems into barren land or grasslands.

Moreover, compared to similar studies in Inner Mongolia and Shanxi, we observe that Yulin City experienced a more pronounced reduction in cultivated land, largely due to the stronger enforcement of ecological restoration policies. Additionally, while other regions also reported urban expansion, our study uniquely highlights the disproportionate growth of built-up land in ecologically sensitive zones, raising concerns about potential environmental tradeoffs.

Changes in landscape ecological risk

Landscape ecological risk assessment is essential for understanding the environmental consequences of land use change. Our results indicate that from 1985 to

2020, Yulin City’s ecological risk exhibited a fluctuating trend, increasing initially, then declining, and rising again. Specifically, high-risk and relatively high-risk areas expanded significantly between 1985 and 1990, before decreasing between 1990 and 2000, likely due to ecological restoration efforts. However, after 2000, the proportion of medium to high-risk areas increased again, reaching a peak in 2010, before stabilizing between 2010 and 2020. Spatially, ecological risk was concentrated in areas experiencing rapid land use change. High-risk zones were primarily located in western, southern, and northern Yulin, where industrial activities and coal mining intensified. Conversely, the central region, where large-scale afforestation and desertification control programs were implemented, saw a decline in ecological risk. Our findings are consistent with studies assessing ecological risk in China’s arid and semi-arid regions (Zhang et al., 2020). However, unlike other studies that primarily attribute risk changes to climate variability, our research highlights the dual role of human activities—both as drivers of increased ecological risk and as mitigating factors. Another key difference is our observation that ecological risk initially declined between 1990 and 2000 before rising again, a pattern not widely reported in previous research (Liao et al., 2024). This suggests that early-stage ecological restoration efforts were effective but may have been offset by subsequent industrial expansion, emphasizing the need for long-term, sustainable land management strategies (Su et al., 2025).

Spatial autocorrelation analysis of landscape ecological risk

Understanding the spatial clustering of ecological risk helps in designing targeted land management strategies. Our global autocorrelation analysis using Moran’s I statistic revealed that the spatial clustering of ecological risk weakened from 1990 to 2010, before strengthening again by 2020. The highest spatial autocorrelation was observed in 1990, followed by a decline until 2010, and then a resurgence. Local autocorrelation analysis further indicated that high-risk areas were mainly concentrated in western, southern, and northern Yulin, where industrial activities were most intense. These regions experienced significant landscape fragmentation due to rapid urban expansion and coal mining. In contrast, low-risk zones were concentrated in central Yulin, where ecological restoration efforts had a noticeable impact. Previous research on spatial ecological risk patterns has generally confirmed that industrial and urban expansion increase risk clustering. However, our study uniquely identifies a temporal shift in risk clustering, with a notable decline in spatial aggregation between 1990 and 2010, followed by a resurgence. This suggests that while ecological restoration efforts initially disrupted risk clustering, subsequent urbanization and industrial growth reinforced it. Additionally, our study highlights how regional development policies influenced spatial patterns of risk, an aspect not extensively covered in previous research. This suggests that policy interventions can actively shape ecological risk landscapes, either mitigating or exacerbating risks depending on their implementation.

In particular, the expansion of agricultural land and the process of urbanization in the western and northern regions of the study area have led to an exacerbation of soil erosion, posing a significant threat to the stability of local ecosystems. Furthermore, the reduction in forest and grassland areas—especially in the southeastern and central regions—has resulted in habitat loss and a decline in biodiversity. Additionally, the encroachment of agricultural and industrial zones into critical ecosystems that sustain water sources has contributed to a decrease in water resource availability, particularly in

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areas severely affected by urbanization. These factors collectively contribute to spatial risks within the ecology of the study area.

Our study provides a comprehensive analysis of land use change and its ecological consequences in Yulin City from 1985 to 2020. The findings highlight the success of ecological restoration policies in increasing grassland and forest areas but also reveal the growing environmental risks associated with rapid urban expansion and industrial activities. Compared to previous studies, our research offers a more detailed spatial and temporal analysis, shedding light on the complex interactions between land use policies, economic development, and ecological risk.

Conclusion

This study provides a comprehensive analysis of land use changes and the associated ecological risks in Yulin City from 1985 to 2020. The findings reveal significant shifts in land use types, with grassland expanding substantially, built-up land growing rapidly, and cultivated land decreasing. These changes reflect both natural processes and human interventions, especially the successful implementation of the “Grain for Green” policy, which contributed to the conversion of cultivated land into forest and grassland.

Ecologically, the region experienced fluctuating trends in risk, with periods of increased ecological risk followed by improvement due to policy-driven restoration efforts. The analysis of spatial autocorrelation demonstrated that the ecological risk landscape showed a weakening aggregation until 2010, after which spatial clustering of high-risk areas began to re-emerge. These results underscore the complex interplay between urban expansion, industrial development, and ecological restoration.

The study highlights both the successes and challenges of land use planning in Yulin City. While ecological restoration programs have reduced risk in some areas, rapid urbanization and industrial expansion in others have contributed to increased ecological risks. As Yulin continues to develop, careful land use management and sustainable development practices are essential to mitigate the ecological consequences of further urbanization and industrialization.

Future research should focus on refining the assessment of ecological risk by incorporating a broader range of environmental indicators, including biodiversity and soil quality. Moreover, the impact of socio-economic factors on land use and ecological risk should be further explored to inform more integrated and sustainable land use policies in the future.

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