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Study on the Evolution of Landscape Patterns in Industrial Cities Based on the Evaluation of Ecological Security Levels—A Case Study of Haining City

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Abstract

Against the dual backdrop of rapid urban development and the drive to build an ecological civilization, coordinating industrial growth with ecological protection is crucial for the sustainable development of industrial cities. Using Haining—a typical industrial city—as a case study, this paper analyzes land-use and landscape-pattern evolution with five phases of land-use/land-cover data (1980, 1990, 2000, 2010, and 2020) and constructs an ecological security evaluation system. The results indicate that (1) under policy influences, multiple land types in Haining tended to convert into urban–rural residential construction land; (2) over the past forty years, the landscape pattern became more optimized, and ecological security improved, with increased diversity alongside reductions in fragmentation and contagion; and (3) the overall ecological security level rose significantly during the same period. Sustained macro-level policy regulation is needed to maintain long-term ecological security in industrial cities. The study shows that Haining's ecological security is closely linked to landscape patterns, land-use change, and human disturbance. By tailoring development strategies for different stages, ecological security and sustainable development can be effectively supported, offering guidance for Haining and industrial cities worldwide.

Keywords: industrial city; land use; ecological security evaluation; landscape pattern evolution

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Academic Editor: Alejandro Rescia

Received: 8 September 2025
Revised: 17 October 2025
Accepted: 24 October 2025
Published: 27 October 2025

Citation: Zhang, W.; Du, C.; Shi, Y.; Liu, X. Study on the Evolution of Landscape Patterns in Industrial Cities Based on the Evaluation of Ecological Security Levels—A Case Study of Haining City. *Sustainability* **2025**, *17*, 9539. https://doi.org/10.3390/su17219539

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1. Introduction

In recent years, the processes of international industrialization and urbanization have accelerated, and resource-intensive regions have rapidly expanded, giving rise to a growing number of "industrial cities" dominated by resource exploitation and heavy industries worldwide. However, while these industrial cities continue to release economic and social vitality, they simultaneously exert negative impacts on the urban ecological environment [1]. In particular, the "extensive and outward-expansion" land use model in the construction of industrial cities has encroached upon agricultural land and ecological land, seriously hindering the sustainable development of industrial cities, and making ecological security issues increasingly severe. Against this background, China proposed the "National Sustainable Development Plan for Resource-Based Cities (2013–2020)", and the United Nations launched the Sustainable Development Goals (SDGs), both aiming to

emphasize urban ecological security, industrial green transformation, and circular economy construction. Therefore, under the conditions of increasing ecological pressure and land use imbalance, it is urgent for China and the international community to guide industrial cities toward green, circular, and sustainable development through planning in order to ensure their ecological security.

Industrial cities refer to cities dominated by industry as the leading sector, where industry occupies a dominant position in the urban economic structure. The ecological security problems of industrial cities are characterized by complexity, systematicity, and long-term persistence, which not only affect the health and quality of life of urban residents but also restrict the spatial extent of sustainable urban development [2]. Although the research on industrial cities has gradually increased, several deficiencies remain: in terms of research content, existing studies mainly focus on ecological restoration strategies, and substantial progress has been made in areas such as industrial city air pollution [3], water ecological management [4], soil remediation [5], and vegetation restoration technologies [6]. However, systematic studies on ecological security and landscape pattern evolution of industrial cities under the background of territorial spatial planning are relatively insufficient. In terms of research perspective, most studies have focused on regions with abundant resource endowments and large-scale cities [7,8], while insufficient attention has been paid to the ecological security dilemmas of resource-depleted industrial cities, particularly medium- and small-sized industrial cities characterized by regional industrial transformation and land restructuring. These cities often face more difficult situations in terms of weakened ecological functions and accumulated environmental risks. Therefore, it is necessary to strengthen the systematic analysis of the dynamic evolution of landscape ecological security patterns in small- and medium-sized industrial cities, so as to provide stronger theoretical support and practical guidance for their ecological protection and restoration efforts.

Land use change in industrial cities refers to the process whereby, in the course of industrialization and driven by industrial activities and related socio-economic factors, different types of urban land undergo adjustments and transformations in their spatial distribution and functional attributes [9]. In resource-based cities (RBCs), where resource exploitation is the primary development path, land use change is more intense, with more pronounced structural adjustment and spatial restructuring [10]. Land use change is the direct driving force of urban landscape pattern change [11] and has profound impacts on the ecological security of industrial cities. Most existing studies emphasize the relationship between land use change and the evolution of ecological risk, showing that urban expansion significantly increases the proportion of high-risk ecological security areas [12,13]. Tian Yu et al. combined landscape pattern indices with the human disturbance index (Hemeroby) and, using quantitative methods, depicted the response relationship between human disturbance and landscape pattern evolution during the development of resource-based cities [14]. Li Yanan et al., based on the ArcGIS (ArcMap 10.8) platform and the InVEST habitat quality model, assessed the impact of land use change on habitat ecological quality, revealed the effects of different land use transformations on the ecological habitat pattern of Yanshan County, Jiangxi Province, and, by analyzing the degree of habitat degradation within urban areas, provided new perspectives and methods for ecosystem management and targeted policy-making in mining cities [15]. However, such studies rarely conduct systematic evaluations of the complete chain of interactions among land use, landscape pattern, and ecological security evaluation. Regarding research objects, existing achievements mostly focus on evaluating the security level of single ecological elements in resource-based cities, such as forestry resources [16], wetland resources [17], and mining resources [18]. This perspective is relatively limited and insufficient to capture the complexity and diversity of ecological security issues in industrial cities, where multiple pollution sources, land use

conflicts, and intertwined ecological problems coexist [19]. Moreover, many studies suffer from limited time-series spans and lack the comprehensive application of multi-period time-series data, spatial statistical methods, and systematic evaluation frameworks, making it difficult to reveal in depth the internal connections among long-term dynamic landscape pattern evolution, land use, and ecological security level; as a result, their conclusions remain limited in systematicness and foresight [20–22]. This study draws on forty years of longitudinal data to establish an integrated evaluation framework linking land use, landscape pattern, and ecological security. It uncovers how multiple ecological issues intersect in small- and medium-sized industrial cities, addressing gaps in prior research and providing new perspectives and empirical evidence on the evolution of ecological security.

The ecological security level of industrial cities is closely related to their urbanization level and industrial development process [23]. Industrial cities in foreign countries mostly experienced a peak of industrial transformation during the 1970s and 1980s, and through "deindustrialization" strategies and innovative industrial models, gradually realized the transition from resource-dependent cities to knowledge- and ecology-driven cities, while implementing large-scale urban ecological restoration projects [24]. For example, Germany's Ruhr region has constructed a continuous blue-green corridor network through watershed restoration and brownfield regeneration in the Emscher Landscape Park, significantly improving ecological corridor connectivity and landscape cohesion. Similarly, Madrid, Spain, implemented the "renaturalization" of the Manzanares River, restoring riparian ecological processes and linear green corridors, thereby enhancing ecological connectivity and accessibility in adjacent terrestrial areas. In contrast, the development and transformation of industrial cities in China started relatively late. For decades, they have long relied on resource exploitation and light and heavy industries, characterized by a single industrial structure and great ecological environmental pressure. At present, most industrial cities in China are still in the exploratory stage of transformation [25]. Due to differences in national conditions and development stages, land use patterns, ecological security assessment, and industrial renewal modes in Chinese industrial cities significantly differ from and lag behind those of Western industrial cities. Therefore, selecting domestic industrial cities as research objects has stronger pertinence and application value [26]. Moreover, with China's continuous exploration in the industrial transformation of industrial cities, land use optimization, and landscape ecological security management, its experiences can also provide useful references for global industrial cities still in the stage of resource dependence and transitional difficulties.

Haining is a typical representative of small- and medium-sized industrial cities in China. It has been ranked among the top 100 counties (cities) in China for many consecutive years. Its dominant traditional industries include leather, warp knitting, and home textiles, with a high degree of industrial agglomeration and a complete industrial foundation [27]. In its process of industrialization, landscape pattern evolution driven by land use change and urban expansion has led to common problems faced by resource-based cities, such as overexploitation of natural resources and ecological environmental degradation. How to effectively realize "overall protection, systematic restoration, and comprehensive management" of territorial space, achieve the transformation from industrial city to ecologically livable city, and realize sustainable high-quality development has become a major problem and challenge in the current development of industrial cities. At the same time, these problems not only reflect the common characteristics and development trends of ecological security in many industrial cities in China but also provide useful references and insights for the ecological security governance and sustainable development of similar cities.

In summary, based on the land use type change data of Haining City in 1980, 1990, 2000, 2010, and 2020, this study combines the evolution of landscape patterns in industrial

cities with the evaluation of ecological security levels by using research methods such as the land use transfer matrix, landscape pattern indices, landscape ecological security evaluation, and spatial autocorrelation analysis, with the aim of providing theoretical support and practical guidance for landscape pattern optimization, ecological security improvement, and sustainable development in industrial cities (Figure 1).

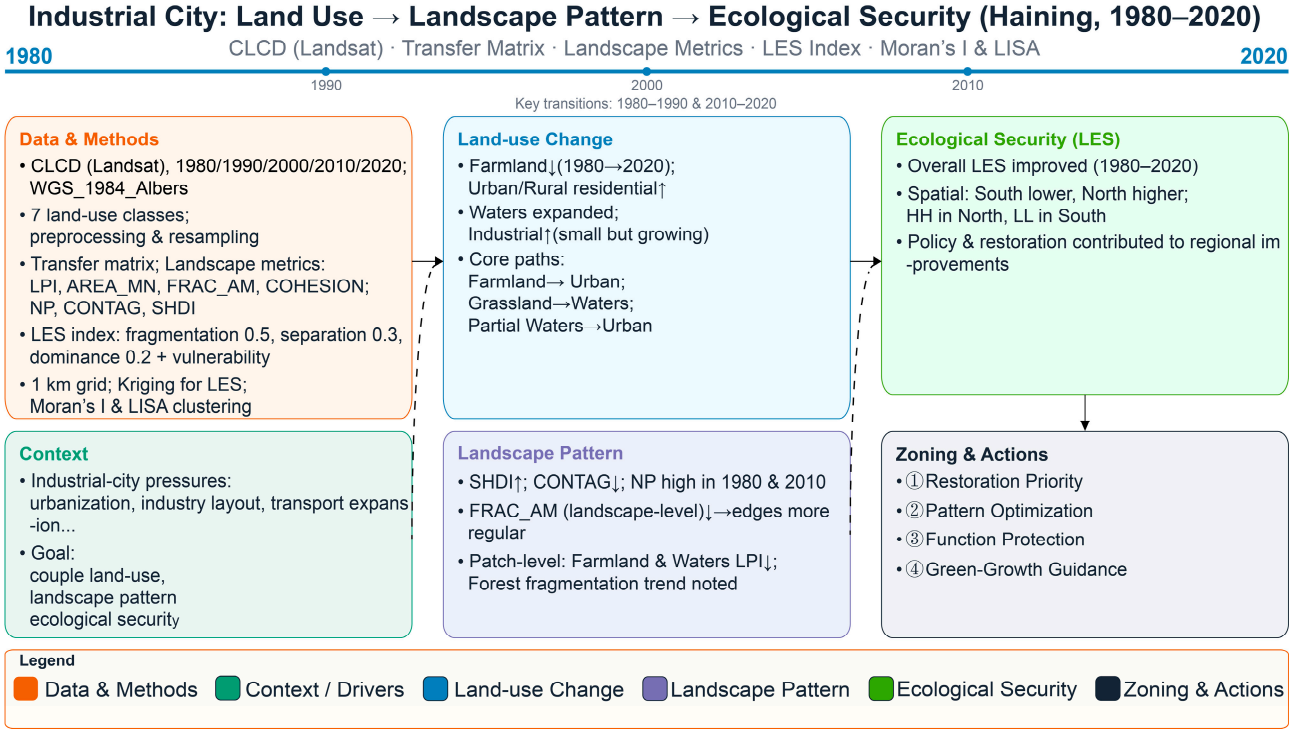


Figure 1. Schematic Diagram of the Research Methodology Process.

2. Materials and Methods

2.1. Overview of the Study Area

Haining City (30° N, 120° E) is located in the northeastern part of Zhejiang Province, China, within the Yangtze River Delta, with a total area of 86,300 ha (Figure 2). Haining belongs to the northern subtropical maritime monsoon climate, characterized by four distinct seasons, with relatively long winters and summers, and short springs and autumns. Except for the hilly areas in the southeast and the elevated zones along the river, climatic differences within the plains are minimal. According to the Bulletin of the Third National Land Survey of Haining City, the main land use types in Haining include farmland (18,433.19 ha), woodland (2580.77 ha), urban, rural, and industrial/mining land (23,766.68 ha), among which urban land accounts for 5355.06 ha. Mining land covers 20.57 ha, accounting for 0.09%, while transportation land accounts for 4546.94 ha, and waters and water conservancy facilities cover 20,798.45 ha (Figure 2).

As an industrial city located in a key position of the Yangtze River Delta urban agglomeration, Haining has a complete industrial chain and a significant park-oriented spatial layout. Its highly developed regional transportation network and infrastructure have promoted active market interactions, while the concentration of population and industrial factors has driven the structural expansion of urban construction land. Consequently, the ongoing reduction of farmland and blue-green spaces has intensified landscape fragmentation, disrupted ecological connectivity, accelerated ecological deterioration, and hindered the momentum for sustainable urban development.

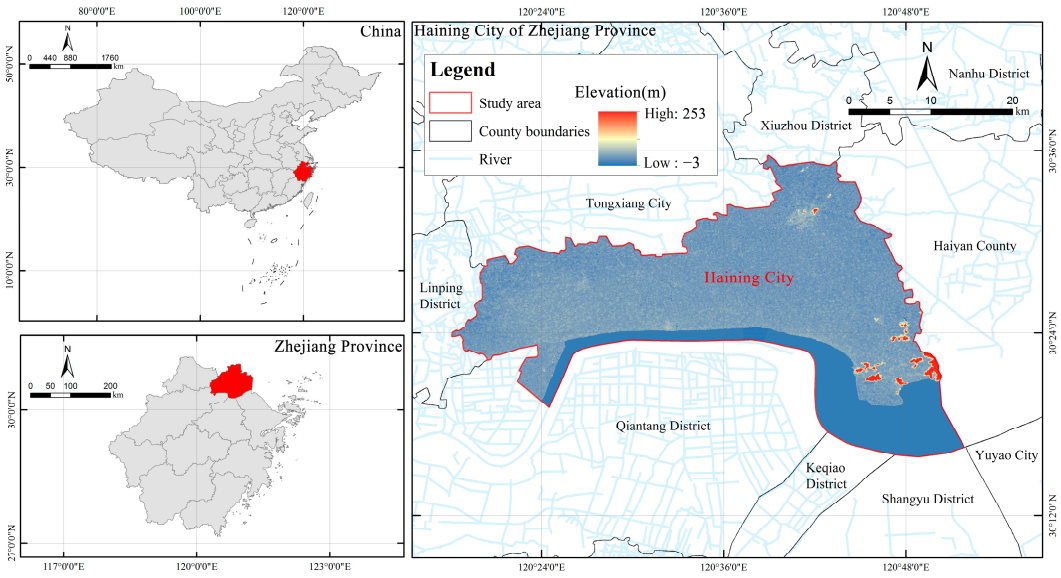


Figure 2. Location Map of the Research Area in Haining City, Zhejiang Province.

2.2. Research Methods

2.2.1. Data Sources and Preprocessing

The land use data adopted in this study are derived from the China Land Cover Dataset (CLCD), developed by Wuhan University, based on Landsat imagery, and generated using the random forest classification algorithm, with an overall classification accuracy of about 80% [28]. To ensure the consistency of spatial data, bilinear interpolation and nearest neighbor resampling were applied to all data, and all data were unified into the WGS_1984_Albers projection coordinate system. Based on the China Land Classification System and the actual land use changes in Haining in recent years, land use types were classified into seven categories: farmland, woodland, grassland, waters, urban and rural residential land, industrial/mining land, and unused land. Considering the spatial resolution of the images and the accuracy of information extraction, land such as factories, large industrial parks, and quarries was uniformly classified as industrial/mining land.

2.2.2. Land Use Change Method

The land use transfer matrix refers to a matrix-form data table generated by overlaying and counting land use change data in a study area during a specific period, which expresses the conversion of different land types into one another during that period [29,30] This study employs land use transfer analysis and transfer matrix methods to examine the spatiotemporal patterns of land use change in Haining, quantitatively capturing the dynamic conversions among different land categories through multi-period vector data overlay analysis.

2.2.3. Landscape Pattern Indices

As a quantitative research method, landscape pattern indices can describe the spatial structure and characteristics of the distribution, shape, size, and connectivity of different land use and cover types within a study area [31]. These indices help reveal the composition and configuration of landscape structures, thus providing an in-depth understanding of the multiple impacts of landscape pattern changes on urban ecological security. To comprehensively reflect the fragmentation and diversity characteristics of landscape patterns in the study area, this study systematically analyzed the landscape pattern changes in Haining at two scales: the patch-type level and the landscape level. Specifically, four patch-level

indices (LPI, AREA_MN, FRAC_AM, and COHESION) and five landscape-level indices (NP, CONTAG, LPI, FRAC_AM, and SHDI) were selected, and each index was calculated using Fragstats 4.2 software.

At the patch level, the four indices are defined as follows: LPI refers to the proportion of the largest single patch in the landscape, usually expressed as a percentage; AREA_MN describes the average area of all landscape patches within a specific region; FRAC_AM measures the complexity of patch shapes; COHESION reflects the degree of spatial connectivity among patches in the landscape.

At the landscape level, the five indices are defined as follows: NP measures the number of all patches in the landscape; CONTAG reflects the degree of spatial aggregation or dispersion of different patch types in the landscape; LPI and FRAC_AM have the same meanings as at the patch level; SHDI is used to measure biological or landscape diversity within a region.

2.2.4. Ecological Security Evaluation

1. Selection of Ecological Security Evaluation Indicators

When conducting an ecological security evaluation, it is necessary to reasonably select landscape ecological indicators that match the research content as the core points of the research design. Existing studies generally adopt the PSR model, that is, the "Pressure–State–Response" model, to construct urban ecological security evaluation systems [32–34]. At the same time, some researchers use the TOPSIS model and the entropy–CRITIC combined weighting to evaluate water ecological security in the study area [35]. However, the above ecological security evaluation models are mostly used at the macro level for assessing urban ecological carrying capacity, and they are relatively subjective. Existing researchers have adopted landscape disturbance and landscape vulnerability to construct urban landscape ecological security index models [36–38]. On the basis of previous research, this study adds landscape dominance as an indicator. On the one hand, landscape dominance can reveal the characteristics of dominance and imbalance in the landscape pattern; on the other hand, incorporating it into the ecological security level evaluation model can improve the completeness and refinement of the evaluation results [39]. At the same time, this indicator helps to understand more deeply the internal mechanisms of the evolution process of ecological security levels in industrial cities, and then to formulate ecological restoration policies and strategies that are more suitable for the study area.

In order to comprehensively evaluate the level of landscape ecological security, this study selects three indicators to construct a calculation system for landscape disturbance, namely landscape fragmentation, landscape separation, and landscape dominance, and introduces landscape vulnerability F_i to carry out weight correction, and finally constructs a landscape ecological security index model. Among them, landscape fragmentation is used to represent the degree of fragmentation of natural and human landscapes in space after being affected by many external factors, which is usually manifested as a complex spatial pattern formed by the weakening of connectivity and the enhancement of isolation among different landscape types (water bodies, grassland, forest, wetland, etc.) within a region [40]; landscape separation refers to an indicator of the degree of spatial distribution dispersion of different landscape types within a given area [41]; landscape dominance is usually a measure of the area and coverage degree of a specific patch type in the overall landscape pattern, and to a certain extent represents its importance or dominant position in a certain area. According to the weight settings in existing research, landscape fragmentation occupies a core position among the indicators of landscape disturbance, with a weight of 0.5, while landscape separation and landscape dominance are 0.3 and 0.2, respectively, so

as to reflect the degree of influence of the factors on landscape disturbance [42]. According to existing research, landscape vulnerability reflects the degree of change in a certain area's landscape use types after being disturbed. Based on the actual situation of the study area and existing research analysis, the vulnerability status of different landscape use types can be divided into five levels: urban and rural residential construction land is the most stable, assigned a value of 1; forest land and grassland are mostly distributed on slopes and are far from places of frequent human activities, and their vulnerability is similar, assigned values of 2 and 3, respectively; farmland, as a land type managed by human cultivation, is easy to change and is assigned a value of 4; water bodies are mostly adjacent to construction land and farmland and are more easily affected by human activities, assigned a value of 5; unused land and industrial/mining land have more fragile ecosystems compared with the above land types and are assigned a value of 6 [43].

2. Determination of Landscape Ecological Security Standards

In order to systematically and scientifically evaluate the landscape ecological security level of Haining and ensure the comparability of time-series analysis within the study area, this study refers to the existing ecological security evaluation practices of resource-based cities [44], and adopts the natural breaks method to classify the landscape ecological security index ES_k into five levels (low security—relatively low security—medium security—relatively high security—high security). The yearly classification interval is taken as the baseline and uniformly applied to the classification intervals of other years. According to the calculation results, the ES_k values are divided into five security levels: when ES_k is between 0.070–0.252, it is defined as low security, in which the regions are characterized by high landscape fragmentation, poor connectivity, and ecosystems prone to external disturbance and instability; when ES_k is between 0.252–0.434, it corresponds to relatively low security, mostly reflecting areas strongly affected by human activities with limited ecological recovery capacity; the medium security level corresponds to ES_k between 0.434–0.616, representing areas with relatively balanced ecological structures but still under moderate anthropogenic pressure; the relatively high security level (0.616–0.798) indicates higher landscape connectivity and stability, with certain ecological regulation functions; the high security level (0.798–0.980) represents areas with high ecosystem integrity, minimal external disturbance, and well-maintained habitat quality. In other words, the larger the landscape ecological security index value, the higher the ecological security level of Haining.

2.2.5. Spatial Autocorrelation Analysis

Global spatial autocorrelation is an important concept in spatial statistics, used to analyze the spatial distribution pattern of a variable across the entire geographic region, and to help determine whether the ecological security level in geographic space exhibits aggregation or randomness. In this study, Moran's I is used for representation. Local spatial autocorrelation, based on global autocorrelation, further examines the relationships between each spatial unit and its neighboring areas in a "magnifying glass" manner, and is used to reveal local spatial anomalies and spatial aggregation patterns. In this study, the LISA index is used for representation. This study adopts a spatial autocorrelation analysis method combining both global and local autocorrelation. The global autocorrelation index reflects whether aggregation or outliers appear in space, while the local autocorrelation can pinpoint clustering at specific locations.

3. Results

3.1. Analysis of Land Use Change

3.1.1. Current Situation of Land Use

From 1980 to 2020, over a forty-year period, the land use pattern of Haining showed significant temporal variation characteristics. Overall, farmland has always been the dominant land use type in Haining, ranking first in area in all years, but its proportion has shown a continuous downward trend, decreasing from 60.42% in 1980 to 49.30% in 2020. The scale of urban and rural residential construction land has continuously expanded, with its proportion steadily increasing from 16.57% to 28.43%, reflecting the acceleration of the urbanization process. Although industrial and mining land accounts for a relatively small proportion of the total area, its expansion has been substantial, nearly tripling from 1980 to 2020. This trend indirectly reflects that the process of urban industrialization in Haining has amplified the fragmentation and morphological simplification of the surrounding landscape pattern. In terms of spatial distribution pattern, urban and rural residential construction land in Haining was initially concentrated in the northern urban areas and later extended to the southern and eastern regions. Farmland was distributed throughout the city and not limited to specific areas. Waters were mainly located in the southern part of the study area, woodlands were mostly concentrated in the southwest, while industrial and mining land was scattered, distributed in point-like forms in some eastern, western, and southern areas (Table 1).

Table 1. Land Use Change in the Study Area from 1980 to 2020.

Land Use Type	1980		1990		2000		2010		2020	
	Area/ha	Percentage/%	Area/ha	Percentage/%	Area/ha	Percentage/%	Area/ha	Percentage/%	Area/ha	Percentage/%
Farmland	524.13	60.42	528.64	60.94	510.64	58.86	496.77	57.27	427.65	49.30
Woodland	11.18	1.29	12.80	1.48	12.48	1.44	13.22	1.52	12.46	1.44
Grassland	28.24	3.26	0.36	0.04	0.33	0.04	0.33	0.04	8.66	1.00
Waters	155.41	17.91	186.15	21.46	190.21	21.93	157.47	18.15	154.91	17.86
Urban and Rural Residential Land	143.71	16.57	137.46	15.85	151.48	17.46	187.30	21.59	246.59	28.43
Industrial and Mining Land	4.82	0.56	2.02	0.23	2.34	0.27	12.40	1.43	17.22	1.99
unused land	0	0	0.04	0.004	0	0	0	0	0	0

3.1.2. Land Use Structure Change

From 1980 to 2020, the land use pattern of Haining experienced significant adjustments, with the mutual transformation among farmland, urban–rural construction land, grassland, and water areas constituting the core pathway of land use evolution. Among these, the conversion of farmland to urban and rural residential construction land was the largest in scale and exhibited a continuous transfer trend. Meanwhile, 5.5 hectares of water bodies were converted into urban–rural construction land, with parts of wetlands and aquatic resources replaced by construction activities (Figure 3 and Table A1). These changes were mainly concentrated in the northern and southeastern parts of Haining, reflecting the spatial compression of agricultural and ecological spaces caused by urbanization and the increasing demand for industrial land. This indicates that, under the context of rapid industrialization, the urbanization process has become the primary driving force behind the transformation of land use structure, while also intensifying spatial competition among different land types and restructuring ecological functions.

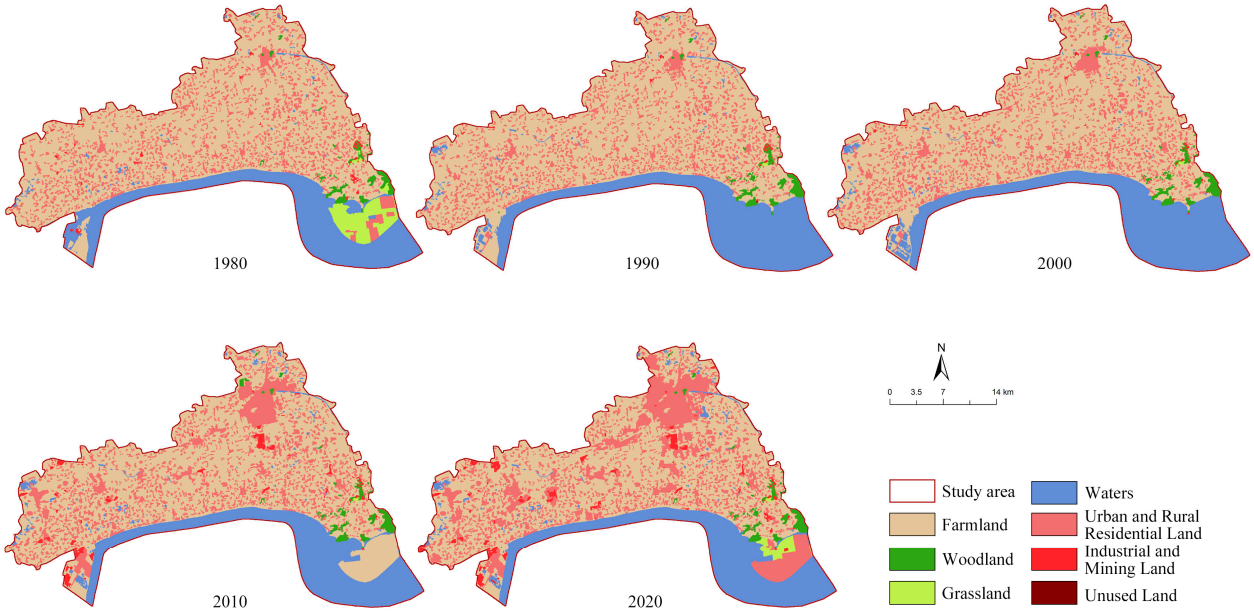


Figure 3. Land Use Change in Haining City from 1980 to 2020.

From the perspective of spatial and temporal evolution, different land use types in Haining showed distinct stage-based differences and conversion characteristics between 1980 and 2020. In particular, two periods—1980–1990 and 2010–2020—witnessed the most significant land use adjustments. During 1980–1990, the water area in Haining expanded noticeably, with most of the newly added water bodies converted from grassland, accompanied by minor adjustments involving farmland and construction land. Meanwhile, a slight replenishment of farmland was also observed (Figure 3 and Table A2). These changes were mainly concentrated along the southeastern waterfront zone, indicating that early urban development oriented toward water resources, together with water system management, jointly promoted the reorganization of blue–green spatial structures. From 2010 to 2020, land use changes in Haining exhibited a dual-driven pattern. On the one hand, the implementation of national ecological restoration policies—such as "returning farmland to forest" and "returning farmland to grassland"—encouraged the transformation of degraded farmland into ecological land, thereby enhancing the connectivity and cohesion of ecological restoration zones. On the other hand, rapid economic growth and urbanization in China strongly accelerated the large-scale conversion of farmland into construction land, mainly concentrated in the northern and southeastern parts of the study area (Figure 3 and Table A3). During this period, the former process, driven by ecological restoration initiatives, improved the structural connectivity of the landscape and generated stable clusters of high-value ecological zones, whereas the latter led to increasing fragmentation of landscape patterns in the north and southeast. Therefore, strategies such as strengthening ecological buffer zones and promoting the renewal of existing land should be adopted to mitigate the spread of fragmentation.

Overall, from 1980 to 2020, Haining's land use pattern underwent significant transformations, with the expansion of urban and rural construction land and the reduction of cultivated land being particularly evident. The changes in land use structure over these forty years reflect that land development and utilization were strongly influenced by factors such as industrialization, urban expansion, industrial layout adjustments, and improvements in the transportation network (Figure 3).

3.2. Analysis of Landscape Pattern Change

3.2.1. Patch-Scale Change Analysis

From the time-series evolution of the mean patch area (AREA_MN) index, it can be seen that farmland in Haining always maintained a relatively high mean patch area during the study period. This means that farmland had the strongest spatial continuity and the lowest degree of landscape fragmentation. Since the 1980s, the mean patch area of farmland continued to expand, reaching its peak in 2000, indicating that landscape fragmentation was at its lowest during that period. However, after 2000, with the rapid advancement of urban–rural construction and industrialization, the overall connectivity of farmland began to weaken, the trend of patch fragmentation gradually appeared, and the degree of landscape fragmentation increased. By contrast, the patch areas of urban and rural residential land, industrial development land, and unused land were significantly smaller and highly dispersed. The reason was closely related to activities such as deforestation, mining development, and construction land occupation, which caused originally continuous farmland or grassland to be transformed into scattered artificial construction sites (Figure 4).

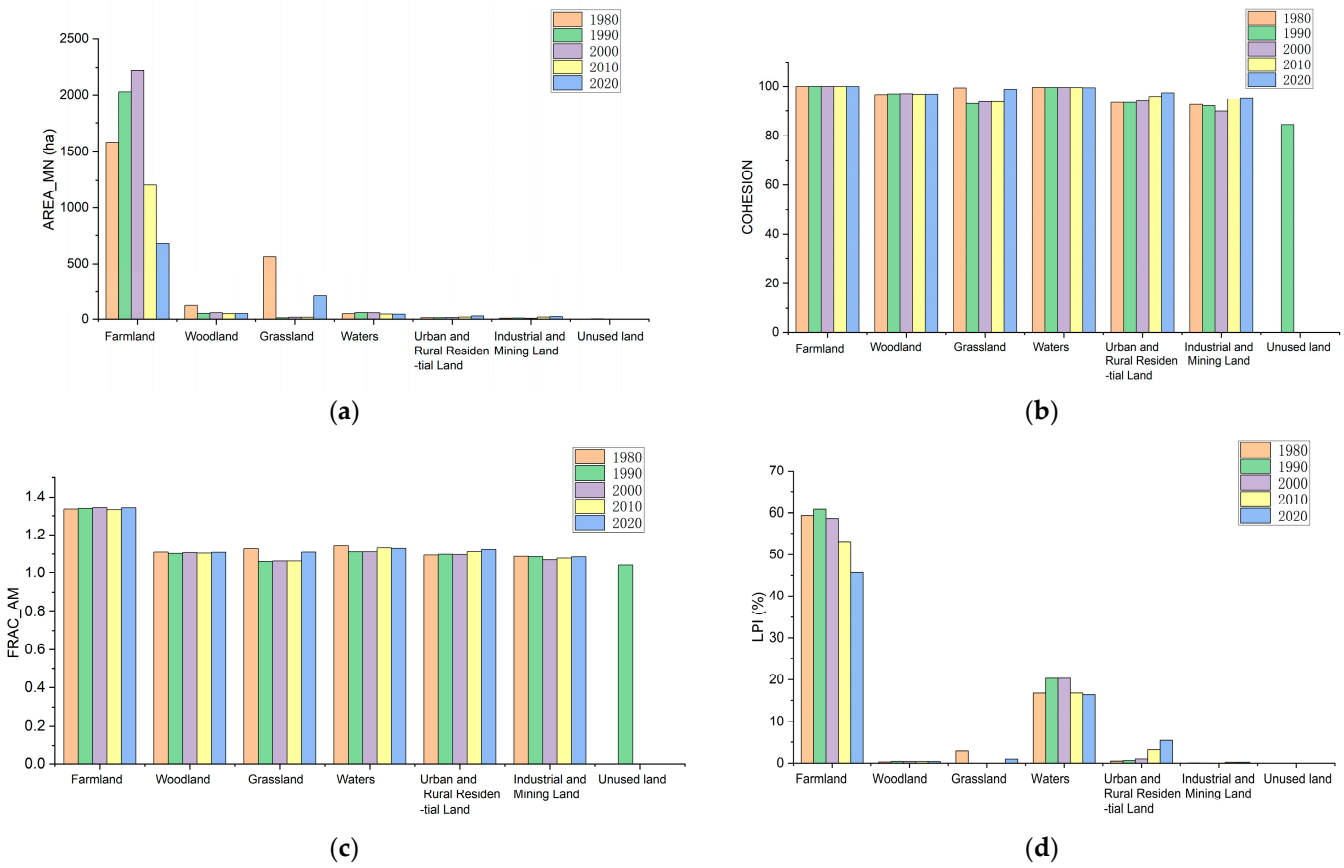


Figure 4. Changes of Patch-Scale Landscape Pattern Indices in Haining from 1980 to 2020. (**a**) 1980–2020 AREA_MN index change; (**b**) 1980–2020 COHESION index change; (**c**) 1980–2020 FRAC_AM index change; (**d**) 1980–2020 LPI index change.

From the time-series change of landscape cohesion (COHESION), except for unused land, the aggregation index of all other land types maintained a level close to the maximum value over forty years, showing strong spatial dependence and overall connectivity among patches. The cohesion of unused land was significantly different from other land types. In 1980, 2000, 2010, and 2020, its value was 0, and this land type was absent in most years of land conversion and development. It only appeared briefly in 1990 due to the conversion

of a mining land in the southwest coastal area. Limited by its extremely small area and sparse distribution, the cohesion of this land type was very low (Figure 4).

From the time-series change of the area-weighted mean patch fractal dimension (FRAC_AM), the FRAC_AM value of farmland remained the highest among all land types during the forty years, stabilizing at around 1.3, which indicates that its patch boundaries were more tortuous and complex, and the irregularity of edges was significantly stronger than other land types. The FRAC_AM values of woodland, grassland, and waters were relatively close, mostly remaining around 1.0, reflecting that the patch boundaries of these land types were relatively straight and regular in shape. It is worth noting that the FRAC_AM value of grassland showed a stage decline in 1990 and rose again in 2010. This change was influenced by the gradual introduction and implementation of ecological protection policies such as returning farmland to grassland. At the early stage, artificial intervention caused the grassland boundaries to become more regular, and with the advancement of natural recovery, the boundary complexity increased again. This trend was consistent with the stage fluctuations shown in the chart data. By contrast, the FRAC_AM value of urban and rural residential land showed a gradual upward trend after 2000, indicating that during the urban development process, this land type tended to become more regular in shape, and its boundary lines were simplified, reflecting the orderliness and standardization in construction land development (Figure 4).

In terms of the Largest Patch Index (LPI), farmland and waters were always the dominant landscape types in Haining, but their time-series trends diverged significantly. From 1980 to 1990, farmland LPI showed an upward trend, but after 1990, it declined rapidly, which contrasted with the steady increase of the LPI of urban and rural residential land. Combined with the actual situation of urbanization and industrialization in the study area, this trend directly reflected the continuous encroachment of farmland by the expansion of construction land. The LPI of waters exhibited a stage evolution of first increasing and then decreasing. The initial increase was mainly due to the conversion of grassland into waters, while the later decline was influenced by some waters being converted into farmland and other development activities. Overall, the time-series changes of LPI for different land types showed clear stage characteristics, which were consistent with the results of the land use transfer matrix and policy background analysis (Figure 4).

3.2.2. Landscape-Scale Change Analysis

From the change of area-weighted mean patch fractal dimension (FRAC_AM), the overall trend from 1980 to 2020 showed a slow decline, decreasing from 1.2497 to 1.2306, with a reduction of 0.02. This change indicates that the complexity of patch shapes and the tortuosity of boundaries gradually decreased, tending towards geometric regularization and edge smoothing, reflecting a trend of weakening spatial heterogeneity. This trend was related to the centralized renovation of urban construction land and some agricultural land, as such human interventions resulted in the regularization and simplification of patch boundaries (Figure 5).

The Largest Patch Index (LPI) declined from 59.40% in 1980 to 45.62% in 2020, showing that the dominance of farmland and waters in the landscape was significantly weakened, which meant that farmland was compressed in scale, while the overall landscape dominance shifted towards diversification. According to the land use change data, this trend was mainly caused by the large-scale expansion of urban and rural residential construction land, which formed new relatively dominant landscape patches in local areas (Figure 5).

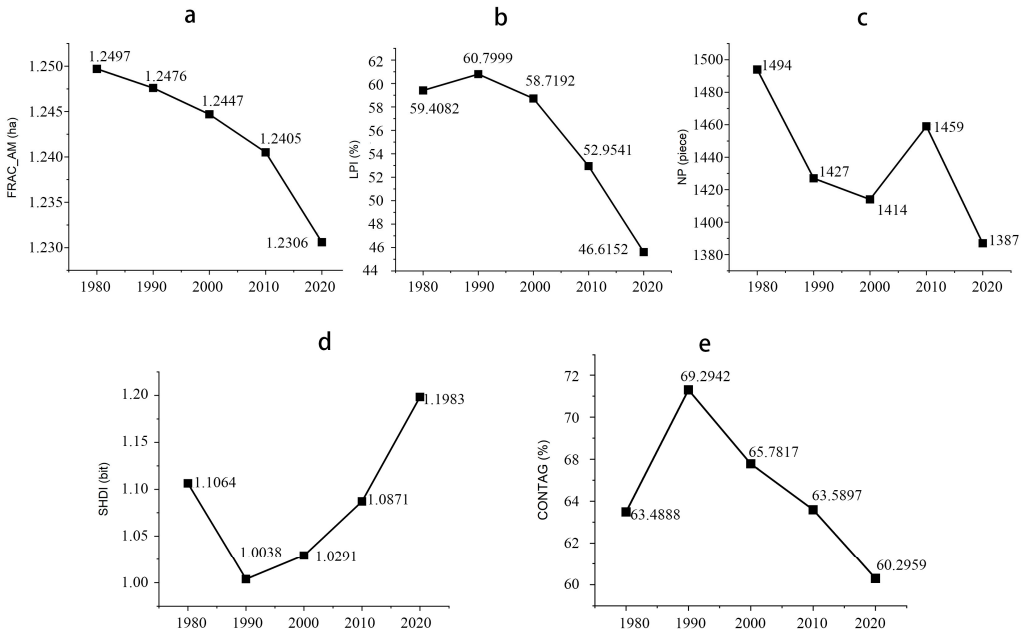


Figure 5. Changes of Landscape-Scale Indices in Haining from 1980 to 2020. (**a**) 1980–2020 FRAC_AM index change; (**b**) 1980–2020 LPI index change; (**c**) 1980–2020 NP index change; (**d**) 1980–2020 SHDI index change; (**e**) 1980–2020 CONTAG index change.

In terms of the Number of Patches (NP), local high values appeared in 1980 (1494 patches) and 2010 (1459 patches), reflecting that the landscape fragmentation was higher in these two periods and the spatial distribution of patches was more discrete. By 2020, NP decreased to 1387, the lowest value during the forty years, which meant that the connectivity among different landscape types increased, landscape continuity improved, and overall stability of the structure recovered to some extent, enhancing the ecological system's resilience to disturbance (Figure 5).

Shannon's Diversity Index (SHDI) showed a steady increase from 1990 (1.0038) to a peak of 1.1983 in 2020, reflecting that the composition of landscape types in Haining became richer and more balanced. This steady growth trend was partly due to the promotion of ecological restoration policies such as returning farmland to forest and grassland, and partly due to the acceleration of urbanization which increased the diversity of urban residential land and transportation land types, indirectly enhancing the heterogeneity of the urban landscape (Figure 5).

The Contagion Index (CONTAG) declined continuously from 59.29% in 1990 to 50.30% in 2020, with a cumulative decrease of 9%, reflecting that the adjacency and spatial aggregation among different landscape patches were significantly weakened. This trend indicated that over forty years, the spatial pattern of Haining's landscape gradually shifted from large continuous patches to a pattern of small patch mosaics. This development trend was closely related to human activities such as industrial park layout, road construction, and urban expansion under the background of rapid urbanization (Figure 5).

3.3. Evolution of the Landscape Ecological Security Pattern

3.3.1. Overall Pattern of the Landscape Ecological Security Index

From 1980 to 2020, the level of landscape ecological security in Haining showed an obvious spatial differentiation in the time series. The most prominent feature was that the southern region as a whole was at a lower security level, while the northern region showed a relatively higher security level. Overall, the landscape ecological security level of Haining showed a trend of gradual improvement during this 40-year period (Figure 6).

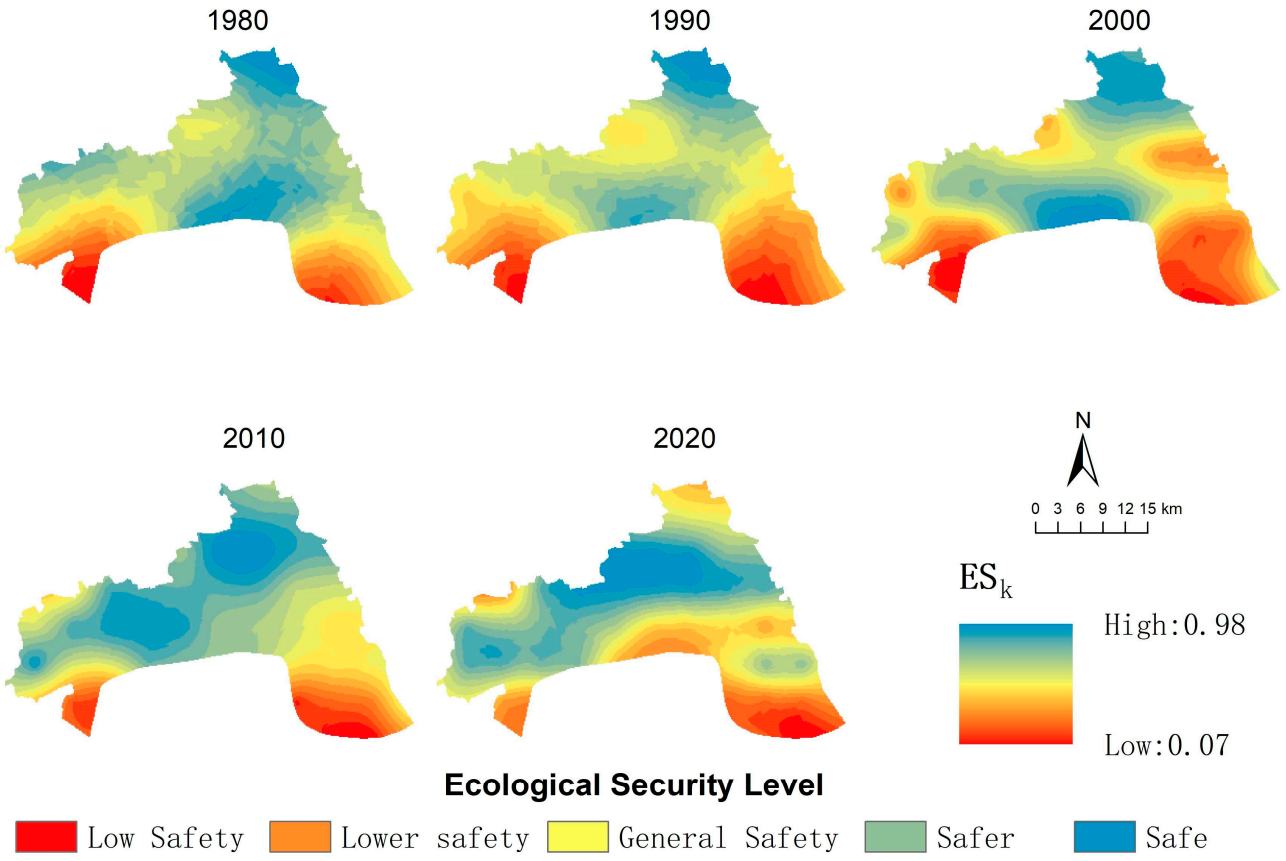


Figure 6. Evolution of the Landscape Ecological Security Level in Haining from 1980 to 2020.

In 1980, the areas of low-security zones and relatively low-security zones in Haining accounted for 0.11% and 11.69% of the total area of the city, respectively, mainly concentrated in the southern part of the city. In these southern regions, farmland, urban and rural residential construction land, water areas, and industrial/mining land were interlaced, resulting in a high degree of landscape fragmentation and at the same time weakening ecological connectivity. In contrast, relatively high-security zones and high-security zones were mainly distributed in the northern and eastern parts of the study area. These regions together accounted for 64.51% of the total area, with land types dominated by farmland and urban/rural residential construction land, forming a relatively continuous and more complete landscape pattern.

Between 1990 and 2000, the overall landscape ecological security level still maintained the "low in the south and high in the north" pattern, but the low-security and relatively low-security zones in the south showed a gradual northward expansion, with their total proportion increasing from 19.54% in 1990 to 27.16% in 2000. The reason was that during this period the ecological environment of Haining was subject to strong human disturbance, leading to a decline in landscape ecological security. At the same time, the areas of high-security zones at both the southern and northern ends increased, which was closely related to the expansion of urban and rural residential construction land.

During the period from 2010 to 2020, the landscape ecological security pattern of Haining gradually evolved from "low in the south and high in the north" to "low in the southwest and high in the northeast." The ecological security level in the central region declined, whereas the security level in the northern region rose. In 2010, the proportion of low and relatively low ecological security zones dropped to 17.43%, while the proportion of high and relatively high ecological security zones increased to 56.37%, mainly distributed in waters, reflecting that ecological restoration policies and projects

achieved remarkable results during this period. By 2020, along with the outward expansion of urban and rural construction land, landscape connectivity gradually increased, and a large ecological security area formed in the central region, accounting for 15.67%. The low ecological security zone in the southwest shrank significantly, and low ecological security zones appeared in the southern and northern regions, mainly affected by the accelerated urbanization process and the local increase of industrial/mining land. Compared with 2010, the overall landscape ecological security level showed a slight decline.

3.3.2. Spatial Autocorrelation Analysis of the Landscape Ecological Security Index

Between 1980 and 2020, the global Moran's I values of the study area were 0.473, 0.588, 0.661, 0.626, and 0.643, all of which passed the test at the significance level of $p = 0.01$, indicating that the spatial distribution of Haining's landscape ecological security index was not random but showed a sustained and significant positive spatial correlation. Based on the identification of clustering locations, this study combines local spatial autocorrelation with multi-year landscape indicators for joint analysis. The results show that the high–high clustering areas were continuously distributed in the northern farmland and forest regions during 1980–2020, while the low–low clustering was concentrated in the southern urban–rural construction land and water areas. Compared with the "non-significant" regions, the high–high clustered grids exhibited higher dominance and connectivity, weaker fragmentation, and more regular patch shapes; for example, the LPI, COHESION, and CONTAG indices remained high, whereas NP and FRAC_AM were lower, and AREA_MN was larger. In contrast, the low–low clustered grids showed increases in NP and FRAC_AM, while COHESION and CONTAG presented a decreasing trend, indicating that the landscape ecology became more fragmented and cohesion weakened. These differences remained relatively stable over time, while the evolutionary trajectories of the high–high and low–low clustering regions showed local changes with land-use transformations; for instance, human activities such as the conversion of southern farmland into urban–rural construction land and the restoration of northern ecological corridors affected the long-term variations of landscape indices and spatial autocorrelation data. Overall, land-use transformation has promoted the reorganization of landscape patterns, thereby producing multiple impacts on the spatial heterogeneity of ecological security, and this mechanism chain is strongly supported by the long-term visualized data and chart analyses (Figure 7).

From the perspective of temporal variation, in 1980, the distribution of high–high and low–low units was relatively scattered, and the spatial pattern was not concentrated. From 1990 to 2000, the spatial clustering pattern gradually stabilized, and the low–low clustering area in the central and southwestern regions showed a clear trend of expansion, reflecting that during this period the development of urban and rural construction land in this region led to a decline in ecological security levels and increased ecosystem vulnerability. At the same time, the high–high clustering zone in the north remained basically stable. Woodland and farmland, as the main landscape categories in the northern region, played a core barrier role in maintaining regional ecological security during this period.

From 2010 to 2020, the central low–low clustering gradually shifted to the southern region, while the range of the northern high–high clustering zone remained relatively stable. During the stage of rapid urbanization, the adjustment of land use structure guided the central region to implement more reasonable planning. Urban and rural residential construction land gradually aggregated into relatively regular large patches, the edge effect was gradually weakened, and ecological disturbance to surrounding areas decreased accordingly. In contrast, due to the development and continuous expansion of industrial and mining land in the southern region, the ecological security level declined, the low–low clustering significantly increased, and the risk of ecological degradation also rose.

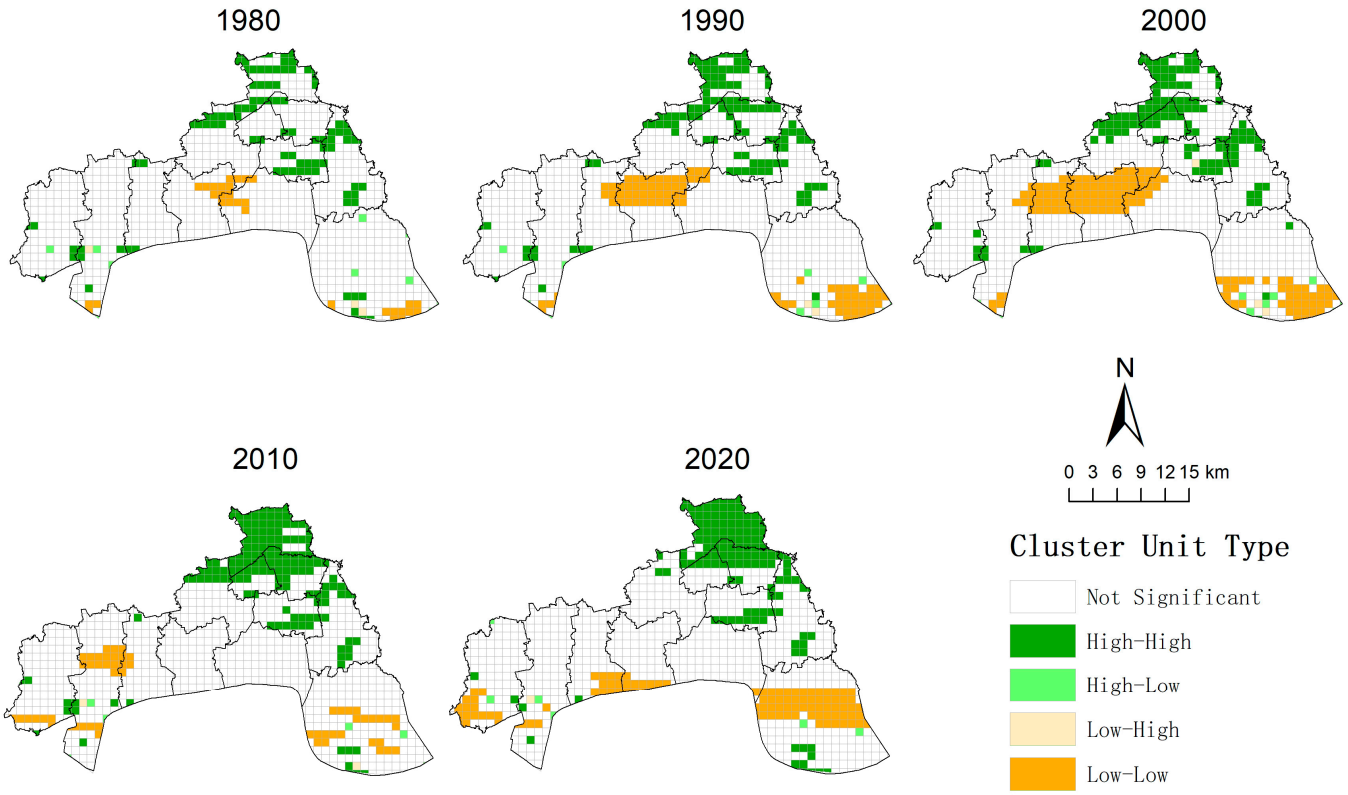


Figure 7. Local spatial autocorrelation maps of the landscape ecological security index in the study area, 1980–2020 (P = 0.01).

4. Discussion

4.1. Driving Mechanism and Causal Relationship of Land Use Change on Landscape Pattern Evolution

To systematically reveal the driving mechanisms and action pathways of land use change on the evolution of landscape patterns, and to construct the coupled logic among "land use–landscape pattern–ecological security" (Figure 7), it is necessary to focus on the causal relationship between land use change in the study area and the evolution of the local landscape pattern. This is mainly reflected in two aspects: the perspective of ecological protection and governance policies and the perspective of socio-economic drivers.

From the perspective of ecological protection and governance policies, over the forty-year period, farmland has consistently been the dominant land type in Haining, maintaining a large average patch area and a relatively high FRAC_AM value, but its integrity has been weakened under the pressure of urban construction and industrialization. With the continued implementation of cultivated land protection and ecological restoration policies—such as the Reply of the People's Government of Zhejiang Province on the Overall Land Use Plan of Haining City (2016), which emphasizes "cherishing land, rational utilization, and effective protection of farmland"—the rate of farmland reduction has gradually slowed, and the farmland structure has tended to stabilize. Under the combined effects of "returning farmland to grassland" and natural recovery, the boundary morphology of grassland has shifted from regular to more complex, increasing morphological diversity and enhancing local connectivity potential. Urban–rural residential construction land, constrained by planning rectification, has shown a slight increase in FRAC_AM and overall regularity of shape, but it still exerts pressure on surrounding ecological patches. Overall, policy interventions have, to a certain extent, effectively curbed the fragmentation of the landscape pattern and maintained key regional ecological functions; however, it remains necessary to

further consolidate landscape connectivity through rigid farmland protection, continuous ecological buffer zones, and the management of blue–green corridors.

From a socio-economic driving perspective, Haining, as a typical small- and medium-sized industrial city, has experienced continuous expansion of industrial policies, industrial introduction, and park layouts during its forty years of industrialization. These processes have directly influenced the structural transformation of land types, with a predominant trend toward the concentration of manufacturing and logistics industries. While this has continuously strengthened the development intensity along specific urban corridors, the overall landscape has shown an increase in the number of patches, more regular shapes, proliferated edges, and a gradual rise in fragmentation, accompanied by reduced connectivity and cohesion, ultimately leading to clusters of low ecological security values. The advancement of industrialization and urbanization has accelerated population inflow, which, along with the expansion of urban–rural residential construction land and the spatial separation between workplaces and residential areas, has promoted the development of transportation infrastructure such as railways and expressways. However, this also intensified disorderly land conversion and expansion along transportation corridors, further compressing farmland and ecological buffer zones. Additionally, the discontinuity of cross-regional governance and management boundaries has resulted in insufficient protection of ecological corridor continuity and integrity, while ecological restoration projects and temporal coordination are often constrained. Therefore, attention must be given to the structural land use transformations driven by industrial policies, population pressures, and governance fragmentation, as these factors collectively contribute to the increasing fragmentation of the landscape pattern.

4.2. Ecological Security Regulation and Planning of Haining

Ecological Security Zoning Plan of Haining

As an industrial city dominated by manufacturing, Haining needs to consider multiple conditions such as its own economic development characteristics, natural environmental conditions, and land use change. Combined with the 2020 evaluation of landscape ecological security levels, the risk characteristics and ecological functions of regions with different ecological security grades should be analyzed, and then systematic, scientific, and sustainable zoning control strategies and planning should be formulated. In 2020, the Haining municipal government issued an ecological environment zoning control plan, which mainly delineated ecological zones based on policy red lines, but lacked quantitative analysis of landscape patterns and assessment of landscape ecological security. This study takes the 2020 landscape ecological security index of Haining as the core basis, combined with the requirements of higher-level spatial planning, and makes use of multi-source spatial data, including the current land use pattern, digital elevation model (DEM), and administrative boundary data. Through overlay analysis, spatial interpolation analysis, and relevant geographic information processing methods, the ecological security levels of Haining were spatially identified, and finally divided into four ecological functional zones: key ecological restoration zones, ecological pattern optimization zones, ecological function protection zones, and green development guidance zones (Figure 8).

The southern coastal area, the southeastern riverside area, and parts of the southwestern region of Haining are designated as key ecological restoration zones, including Huangwan Town, the northern part of Yuanhua Town, the riverside area of Dingqiao Town, and the southern part of Xucun Town, with an area of 16,457.41 ha, accounting for 19.07% of the total area (Figure 8). As high-priority land for ecological governance and restoration, this zone should focus on protecting farmland, woodland, and waters, implementing land quality improvement, vegetation restoration, and water system restoration measures. In

addition, considering the actual conditions of manufacturing and regional location in Haining, high-pollution and high-energy-consuming industries should be strictly prohibited from gathering or expanding in this zone, especially enterprises related to printing, leather, and chemical industries with pollution discharge needs. At the same time, in the southern riverside area of Dingqiao Town, reclamation, large-scale urban–rural construction, and other high-intensity human development activities should be forbidden to ensure that this ecologically fragile zone can achieve long-term ecological function restoration and protection.

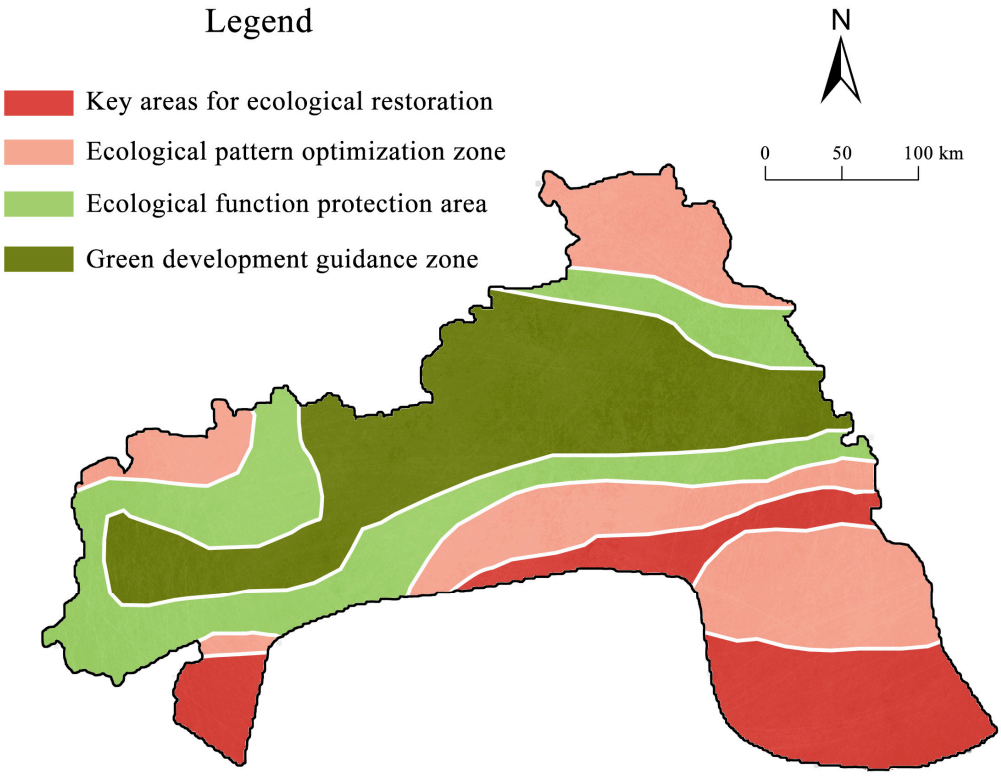


Figure 8. Ecological Security Zoning Plan of Haining City.

The ecological pattern optimization zone is mainly distributed in the buffer belt between the southern coastal area and the central area, as well as in parts of the northern and northwestern regions. This zone includes the boundary area between Huangwan Town and Yuanhua Town, the northern part of Dingqiao Town, the northern part of Shenshi Town, and the area north of Haichang Subdistrict, with an area of approximately 21,997.84 ha (Figure 8). The land use types in this zone are mainly cultivated land and some construction land, and there are many local dominant industrial sectors within the area, such as textile manufacturing, materials and chemical industry, leather processing, and machinery manufacturing. Therefore, this zone is subjected to multiple pressures from urban expansion, the intensive layout of industrial parks, and trunk transportation, resulting in the subdivision of landscape patches and the cutting of ecological corridors. Although it has a certain recovery function, timely intervention with ecological security measures is still needed.

The ecological function protection zone corresponds to the "relatively safe" level in terms of landscape ecological security. This zone is mainly a central belt, serving as a buffer between the northern safe zone and the southern generally safe zone. In geographic terms, it runs through the line of Tanqiao Township–northern Dingqiao Town–southern Guodian Town–western Xucun Town–Shenshi Town, as well as partial belt-shaped areas south of Haichang and north of Xieqiao Town, with an area of 19,193.12 (Figure 8). The

land types in this zone are mainly cultivated land and urban–rural residential construction land, and the riparian waters of the Qiantang River also play an ecological connectivity role here as an important hydrological element. This zone features strong ecological connectivity and a relatively complete ecological structure, with a higher level of ecological security. To maintain and enhance the ecological regulation function of this zone, emphasis should be placed on protecting cultivated land and the river–network pattern, strictly controlling the occupation of newly added construction land, and reducing the intensity of human disturbances.

The green development guidance zone is mainly distributed in the central part of Haining, as well as in parts of the northern and western areas, showing a belt-like extension and forming a surrounding transitional pattern with the ecological function protection zone. This zone has a high degree of ecological structural integrity, good landscape connectivity, and strong natural recovery capacity (Figure 8). Although the ecological security level of this zone is the highest, it still faces environmental pressures during the process of urbanization. On the basis of maintaining the overall pattern of cultivated land and water systems, farmland shelterbelts and riparian vegetation buffer belts should be improved to further enhance landscape connectivity and strengthen ecological security functions. In terms of industrial structure, high-pollution and high-energy-consuming projects should be strictly prohibited, and an eco-friendly industrial chain should be explored. To enhance and maintain ecological security in industrial cities, it is also crucial to reasonably manage and restrict the types, layout, and renewal of regional industries, so as to promote the sustainable development of industrial cities under the premise of ensuring ecological security.

To ensure that strategies for ecological functional zones are effectively implemented, coordinated promotion at the government level is essential. In terms of funding, a dedicated fund for ecological security and functional protection should be established and an annual project funding pool created. Priority should be given to the renewal of existing land, with reasonable selection of inefficient parks for land consolidation. Enterprises should be encouraged to save energy, reduce emissions, and upgrade technologies, with incentives linked to performance indicators such as “no decline in connectivity” and “no increase in fragmentation.” In terms of regulation, red-line boundaries and laws and regulations for penalties and supervision—such as a “Regulation on Urban Land Ecological Security Management”—should be set. Rigid requirements such as “no narrowing of buffer zones,” “no reduction in cross-regional connectivity,” and “no damage to hydrological ecology” should be incorporated into approval thresholds. Zero net increase and capacity limits should be imposed on high-pollution, high-energy-consuming projects, and clear rules should be defined for industry/project admission and enterprise transformation pathways. In terms of law enforcement, leading departments and local responsibilities should be clarified, routine monitoring and assessments should be carried out, and a cross-regional remote sensing monitoring and joint law enforcement mechanism should be established. Heavy penalties and time-limited rectification should be applied to illegal land occupation, over-intensity development, and excessive emissions. Supervision should be strengthened through information disclosure and third-party evaluation, and long-term conservation contracts should be signed with high-quality enterprises to ensure that zoning control and ecological functions remain stable and sustainable.

4.3. Implications for the Planning and Development of Industrial Cities

In industrial cities at the early stage of development, frequent conversions occur among different landscape types, with a high degree of regional landscape fragmentation, continuous increase in landscape shape complexity, and poor landscape connectivity. In future development, unused land should be prioritized for reclamation, and different

land uses should be planned in an integrated manner. For areas with severe landscape fragmentation, measures such as landscape reconstruction and ecological space integration should be adopted in a timely manner to promote the ecological restoration of inefficiently developed land, strengthen the construction of ecological corridors, and enhance the connectivity and integrity of the overall regional ecology.

In industrial cities at the mature stage, landscape ecology still faces the trend of fragmentation and irregularity, with continuous expansion of urban–rural construction land, as well as the degradation and dispersion of natural landscapes. In future development, large-scale and disorderly expansion of industrial land should be prohibited, and inefficient, extensive land use patterns should be avoided. Intensive management and functional improvement of industrial industries should be prioritized, and green development should be advocated. For example, through the renewal and transformation of inefficient factory buildings, optimization of industrial layout, and guidance of infill development of industrial land, land use efficiency can be improved. At the same time, the transformation toward eco-friendly industries should be vigorously promoted, gradually reducing the high-intensity disturbance impact of resource development activities on the natural ecology.

In industrial cities at the transformation stage, the distribution characteristics of urban–rural construction land, farmland, grassland, and woodland landscapes have changed considerably. In order to meet the needs of urban transformation and development, the process of urbanization has accelerated, and ecological natural landscapes are still subject to human disturbances. In future transformation development, on the one hand, traditional industries should be upgraded, actively responding to opening-up policies, improving the level of technological innovation, and accelerating the development of modern service industries. On the other hand, during the transformation process, the protection of basic farmland, woodland, and water systems should be strengthened, and the conversion of such land into industrial land should be strictly controlled.

4.4. Limitations and Future Directions

This study focuses on the evaluation of ecological security patterns and zoning planning in industrial cities, providing a practically targeted analytical framework for ecological protection and spatial optimization in global industrial cities. The results of this ecological security level analysis can offer systematic and scientific references for local governments in formulating ecological space control policies and urban sustainable development planning, and help industrial cities at different development stages to identify ecologically vulnerable areas and adopt regionally differentiated regulation strategies, thereby promoting the ecological security level to develop in a sustainable direction.

However, several limitations of this study still need to be acknowledged. First, in terms of the selection of landscape pattern indices, the control of remote sensing data accuracy, and the setting of ecological security evaluation standards, there is still a lack of high precision, which may lead to certain deviations in the final evaluation results. Future research can further introduce ecological risk assessment models to cross-validate the current results and enhance the robustness of the evaluation. Second, although this study systematically analyzed the spatiotemporal evolution characteristics and spatial distribution patterns of ecological security levels and explored their spatial autocorrelation, the driving factors affecting the ecological security level of industrial cities were not fully and deeply investigated. Follow-up studies need to combine quantitative methods such as geographical detectors and structural equation models, starting from more driving factors such as industrial layout, population density, and distribution, to reveal the impacts of multiple factors on ecological security levels. Finally, the regulation strategies and ecological zoning planning proposed in this study are mostly based on a macro policy perspective, lacking

in-depth discussion of specific implementation paths. Future research needs to link the entire process from strategic guidance to concrete operational implementation, promoting collaborative governance between macro-level theories and micro-level practices.

5. Conclusions

In this research, Haining was chosen as a representative case of an industrial city. A novel attempt was made to link the evaluation of ecological security conditions with the strategic framework of sustainable development in such cities. Using land use transition data, landscape metrics, and a comprehensive ecological security assessment system, this study systematically explored how the evolution of urban land use from 1980 to 2020 affected both the landscape configuration and the levels of ecological security. The outcomes can serve as a reference for other industrial cities that share similar development characteristics and are at comparable stages. Our findings indicate the following:

(1) Rapid industrialization and urban construction activities significantly drove the conversion of farmland into urban–rural residential construction land, which in turn led to landscape fragmentation, reduction of ecological patches, and decreased landscape connectivity. The overall stability and recovery capacity of the ecosystem were negatively disturbed by human activities, and the regional ecological security pattern evolved from stability to a fluctuating trend of ecological risks.

(2) From 1980 to 2020, the evolution of Haining's landscape pattern demonstrated the typical characteristics of a rapidly industrializing city. At the patch scale, most land types, except for farmland, exhibited trends of high fragmentation, simplified morphology, and declining ecological stability, while farmland and water areas maintained their dominant positions and leading roles. At the landscape scale, the diversity of landscape types increased, and both fragmentation and contagion indices decreased, indicating that the spatial organization of land use was gradually optimized. These changes correspond to the implementation of land management policies and ecological governance measures at different stages, suggesting that policy interventions can substantially enhance regional ecological security. Based on this case study, similar industrial cities aiming to improve their ecological security levels should take blue-green corridors and ecological core patches as the structural framework to limit the fragmentation of conversion corridors for construction land while prioritizing cross-regional connectivity and the continuity of riparian buffer zones to strengthen regional ecological security. It is particularly important to enhance the spatial connectivity of landscape patterns in industrial cities, as such connectivity plays a key role in supporting ecological optimization processes, mitigating habitat isolation, and promoting sustainable urban development.

(3) According to the overall ecological security evaluation, spatial autocorrelation analysis, and the identification of clustering characteristics, the overall ecological security planning of Haining should be divided into four regulation zones: key ecological restoration zones, ecological pattern optimization zones, ecological function protection zones, and green development guidance zones. Combined with the land use characteristics, patch properties, and regional industrial layout of different ecological regulation zones, differentiated regulation strategies were proposed, including restricting disorderly urban expansion, strengthening ecological buffer zone construction, and promoting regional industrial transformation. This analytical and identification method can provide theoretical and empirical support for ecological security governance in industrial cities.

(4) From the perspective of spatial structure and ecological function, this paper deepened the correlation mechanism among "land use—landscape pattern—ecological security,"

and constructed an evaluation framework suitable for regulating ecological security risks during the transformation of industrial cities worldwide. Furthermore, this evaluation system can not only diagnose urban ecological vulnerable zones and potential risk zones but also provide a scientific basis for government departments to formulate spatial planning policies for ecological zoning control, with strong operability and practical guidance value.

Author Contributions: Conceptualization, W.Z. and X.L.; methodology, W.Z.; software, W.Z. and C.D.; validation, W.Z. and C.D.; formal analysis, W.Z. and C.D.; investigation, W.Z. and C.D.; resources, W.Z. and C.D.; data curation, W.Z., C.D. and Y.S.; writing—original draft preparation, W.Z. and Y.S.; writing—review and editing, W.Z., C.D. and Y.S.; visualization, W.Z., C.D. and Y.S.; supervision, X.L.; project administration, X.L.; funding acquisition, X.L. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: Data is available on request from the authors.

Acknowledgments: We sincerely thank Liu Xuewen for his generous guidance, and acknowledge the significant contributions of Du Chenqin and Shi Yu to this paper. We also extend our gratitude to the reviewers for their constructive suggestions, which ensured the quality of this work and enhanced its depth. At the same time, all authors of this paper have agreed to this acknowledgment.

Conflicts of Interest: The authors declare no conflicts of interest.

Appendix A

Table A1. Land Use Transfer Matrix from 1980 to 2020.

Unit: ha							
1980 \ 2020	Grassland	Farmland	Industrial and Mining Land	Urban and Rural Residential Land	Woodland	Waters	Total
Grassland	6.49	0	0.35	13.31	1.12	6.97	28.24
Farmland	0	422.45	10.63	83.81	0.71	6.53	524.13
Industrial and Mining Land	0	0.38	3.67	0.69	0.08	0	4.82
Urban and Rural Residential Land	0	0.38	0	143.11	0	0.22	143.71
Woodland	0	0	0.21	0.16	10.57	0.25	11.18
Waters	2.17	4.43	2.36	5.51	0	140.94	155.41
Total	8.66	427.65	17.22	246.59	12.46	154.91	867.49

Appendix B

Table A2. Land Use Transfer Matrix from 1980 to 1990.

Uni: ha								
1980 \ 1990	Grassland	Farmland	Industrial and Mining Land	Unused Land	Urban and Rural Residential Land	Waters	Woodland	Total
Grassland	0	0.36	0	0	0	26.36	1.24	28.23
Farmland	516.68	0	0	0	4.34	2.37	0.71	524.13
Industrial and Mining Land	2.29	0	2.02	0.04	0.38	0.01	0.09	4.82
Urban and Rural Residential Land	2.81	0	0	0	132.15	8.74	0	143.71
Waters	6.41	0	0	0	0.54	148.41	0.05	155.40
Woodland	0.45	0	0	0	0.01	0	10.73	11.18
Total	528.64	0.36	2.02	0.04	137.46	186.15	12.80	867.48

Appendix C

Table A3. Land Use Transfer Matrix from 2010 to 2020.

Unit: ha							
2010 \ 2020	Farmland	Grassland	Industrial and Mining Land	Urban and Rural Residential Land	Waters	Woodland	Total
Farmland	427.65	6.16	4.66	57.55	0.75	0	496.77
Grassland	0	0.33	0	0	0	0	0.333814
Industrial and Mining Land	0	0	12.40	0	0	0	12.40
Urban and Rural Residential Land	0	0	0	187.08	0.22	0	187.30
Waters	0	2.16	0.17	1.20	153.94	0	157.47
Woodland	0	0	0	0.76	0	12.46	13.22
Total	427.65	8.66	17.22	246.59	154.91	12.46	867.49

References

1. Qiong, L. An Index Evaluation for Planning Modern Industrial Cities: The Low Carbon Concept. *Open House Int.* **2017**, *42*, 15–19. [CrossRef]
2. Rahman, M.M.; Alam, K.; Velayutham, E. Is Industrial Pollution Detrimental to Public Health? Evidence from the World's Most Industrialised Countries. *BMC Public Health* **2021**, *21*, 1175. [CrossRef]
3. Lu, X.; Wu, X.; Wang, Y.; Chen, H.; Gao, P.; Fu, Y. Risk Assessment of Toxic Metals in Street Dust from a Medium-Sized Industrial City of China. *Ecotoxicol. Environ. Saf.* **2014**, *106*, 154–163. [CrossRef]
4. Zhou, M.; Li, X.; Zhang, M.; Liu, B.; Zhang, Y.; Gao, Y.; Ullah, H.; Peng, L.; He, A.; Yu, H. Water Quality in a Worldwide Coal Mining City: A Scenario in Water Chemistry and Health Risks Exploration. *J. Geochem. Explor.* **2020**, *213*, 106513. [CrossRef]
5. Soltani-Gerdefaramarzi, S.; Ghasemi, M.; Ghanbarian, B. Geogenic and Anthropogenic Sources Identification and Ecological Risk Assessment of Heavy Metals in the Urban Soil of Yazd, Central Iran. *PLoS ONE* **2021**, *16*, e0260418. [CrossRef] [PubMed]
6. Zhou, S.; Duan, Y.; Zhang, Y.; Guo, J. Vegetation Dynamics of Coal Mining City in an Arid Desert Region of Northwest China from 2000 to 2019. *J. Arid Land* **2021**, *13*, 534–547. [CrossRef]
7. Cen, X.; Wu, C.; Xing, X.; Fang, M.; Garang, Z.; Wu, Y. Coupling Intensive Land Use and Landscape Ecological Security for Urban Sustainability: An Integrated Socioeconomic Data and Spatial Metrics Analysis in Hangzhou City. *Sustainability* **2015**, *7*, 1459–1482. [CrossRef]
8. Wang, Y.; Wang, X.; Zhang, W.; Man, W.; Liu, M.; Jiao, L. Spatiotemporal Evolution of Landscape Ecological Risk and Its Driving Factors of the Beijing–Tianjin–Hebei Major Mineral Belt, 1985–2022. *Sci Rep* **2025**, *15*, 2425. [CrossRef]
9. Nuissl, H.; Siedentop, S. Urbanisation and Land Use Change. In *Sustainable Land Management in a European Context*; Weith, T., Barkmann, T., Gaasch, N., Rogga, S., Strauß, C., Zscheischler, J., Eds.; Human-Environment Interactions; Springer International Publishing: Cham, Switzerland, 2021; Volume 8, pp. 75–99. ISBN 978-3-030-50840-1.
10. Tang, Q.; Wang, J.; Jing, Z.; Yan, Y.; Niu, H. Response of Ecological Vulnerability to Land Use Change in a Resource-Based City, China. *Resour. Policy* **2021**, *74*, 102324. [CrossRef]
11. Zhao, J.; Yu, Q.; Xu, C.; Ma, J.; Liu, W.; Sun, W.; Miao, Y.; Nawaz, T. Integrated Approach for Ecological Restoration and Ecological Spatial Network Optimization with Multiple Ecosystem Functions in Mining Areas. *Ecol. Indic.* **2023**, *156*, 111141. [CrossRef]
12. Liang, X.; Li, Y.; Zhao, Y. Coupling Land Use Analysis and Ecological Risk Assessment: A Study of the Three Gorges Reservoir Area, China. *Mt. Res. Dev.* **2020**, *40*, R1. [CrossRef]
13. Wang, D.; Ji, X.; Li, C.; Gong, Y. Spatiotemporal Variations of Landscape Ecological Risks in a Resource-Based City under Transformation. *Sustainability* **2021**, *13*, 5297. [CrossRef]
14. Tian, Y.; Liu, B.; Hu, Y.; Xu, Q.; Qu, M.; Xu, D. Spatio-Temporal Land-Use Changes and the Response in Landscape Pattern to Hemeroby in a Resource-Based City. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 20. [CrossRef]
15. Li, Y.; Duo, L.; Zhang, M.; Yang, J.; Guo, X. Habitat Quality Assessment of Mining Cities Based on InVEST Model—A Case Study of Yanshan County, Jiangxi Province. *Int. J. Coal Sci. Technol.* **2022**, *9*, 28. [CrossRef]
16. Xu, L.; Yu, H.; Zhong, L. Sustainable Futures for Transformational Forestry Resource-Based City: Linking Landscape Pattern and Administrative Policy. *J. Clean. Prod.* **2025**, *496*, 145087. [CrossRef]
17. Zhou, S.; Chang, J.; Luo, P.; Kang, Y.; Li, S. Landscape Dynamics and Human Disturbance Processes in Wetlands in a Mining City: A Case Study in Huaibei, China. *Environ. Monit. Assess.* **2023**, *195*, 192. [CrossRef]
18. Dong, J.; Guo, Z.; Zhao, Y.; Hu, M.; Li, J. Coupling Coordination Analysis of Industrial Mining Land, Landscape Pattern and Carbon Storage in a Mining City: A Case Study of Ordos, China. *Geomat. Nat. Hazards Risk* **2023**, *14*, 2275539. [CrossRef]

19. Zheng, W.; Guo, B.; Su, H.; Liu, Z. Study on Multi-Scenarios Regulating Strategy of Land Use Conflict in Urban Agglomerations under the Perspective of "Three-Zone Space": A Case Study of Harbin-Changchun Urban Agglomerations, China. *Front. Environ. Sci.* **2024**, *11*, 1288933. [CrossRef]
20. You, M.; Zou, Z.; Zhao, W.; Zhang, W.; Fu, C. Study on Land Use and Landscape Pattern Change in the Huaihe River Ecological and Economic Zone from 2000 to 2020. *Heliyon* **2023**, *9*, e13430. [CrossRef] [PubMed]
21. Fan, Q.; Ding, S. Landscape Pattern Changes at a County Scale: A Case Study in Fengqiu, Henan Province, China from 1990 to 2013. *CATENA* **2016**, *137*, 152–160. [CrossRef]
22. Wang, Y.; Zhao, X.; Zuo, L.; Zhang, Z.; Wang, X.; Yi, L.; Liu, F.; Xu, J. Spatial Differentiation of Land Use and Landscape Pattern Changes in the Beijing–Tianjin–Hebei Area. *Sustainability* **2020**, *12*, 3040. [CrossRef]
23. Yao, J.; Xu, P.; Huang, Z. Impact of Urbanization on Ecological Efficiency in China: An Empirical Analysis Based on Provincial Panel Data. *Ecol. Indic.* **2021**, *129*, 107827. [CrossRef]
24. Shen, H. Experience in industrial transformation of foreign old industrial cities. *Macroecon. Manag.* **2020**, *1*, 85–90. [CrossRef]
25. Chen, Y.; Wang, H. Industrial Structure, Environmental Pressure and Ecological Resilience of Resource-Based Cities-Based on Panel Data of 24 Prefecture-Level Cities in China. *Front. Environ. Sci.* **2022**, *10*, 885976. [CrossRef]
26. Wang, F.; Gu, N. Impact of Ecological Security on Urban Sustainability in Western China—A Case Study of Xi'an. *Environ. Plan. B Urban Anal. City Sci.* **2021**, *48*, 1314–1339. [CrossRef]
27. Ye, J.; Guo, G.; Yu, K.; Lu, Y. Allocation Efficiency of Public Sports Resources Based on the DEA Model in the Top 100 Economic Counties of China in Zhejiang Province. *Sustainability* **2023**, *15*, 9585. [CrossRef]
28. Yang, J.; Huang, X. The 30 m Annual Land Cover Dataset and Its Dynamics in China from 1990 to 2019. Earth Syst. *Sci. Data* **2021**, *13*, 3907–3925.
29. Hu, Y.; Ma, Y.; Zhang, W. Land Use/Cover in China's Land Areas: Spatio-temporal Pattern Change and Driving Forces Analysis. *J. Agric.* **2020**, *10*, 26–35. Available online: https://iac.iacademic.info/nxxb/EN/10.11923/j.issn.2095-4050.cjas20190600085 (accessed on 23 October 2025).
30. Zhou, X.; Chu, Z.; Ji, X. Changes in the Land-Use Landscape Pattern and Ecological Network of Xuzhou Planning Area. *Sci. Rep.* **2024**, *14*, 8854. [CrossRef]
31. Aguilera, F.; Valenzuela, L.M.; Botequilha-Leitão, A. Landscape Metrics in the Analysis of Urban Land Use Patterns: A Case Study in a Spanish Metropolitan Area. *Landsc. Urban Plan.* **2011**, *99*, 226–238. [CrossRef]
32. Tian, S.; Zhang, Y.; Xu, Y.; Wang, Q.; Yuan, X.; Ma, Q.; Chen, L.; Ma, H.; Xu, Y.; Yang, S.; et al. Urban Ecological Security Assessment and Path Regulation for Ecological Protection—A Case Study of Shenzhen, China. *Ecol. Indic.* **2022**, *145*, 109717. [CrossRef]
33. Lai, S.; Sha, J.; Eladawy, A.; Li, X.; Wang, J.; Kurbanov, E.; Lin, Z.; Wu, L.; Han, R.; Su, Y.-C. Evaluation of Ecological Security and Ecological Maintenance Based on Pressure-State-Response (PSR) Model, Case Study: Fuzhou City, China. *Hum. Ecol. Risk Assess. Int. J.* **2022**, *28*, 734–761. [CrossRef]
34. Song, Z.; Zhu, N.; Yang, D.; He, D. Ecological Security Evaluation and Prediction for Coal Resource Cities Based on the PSR Model: A Case Study of Xuzhou, China. *Sustainability* **2024**, *16*, 8461. [CrossRef]
35. Ye, A.; Li, X.; Cai, J.; Deng, Y. Evaluation of Water Ecological Security and Diagnosis of Obstacles in the Yangtze River Delta, China. *Sci. Rep.* **2025**, *15*, 30981. [CrossRef]
36. Nitschke, C.R.; Innes, J.L. Integrating Climate Change into Forest Management in South-Central British Columbia: An Assessment of Landscape Vulnerability and Development of a Climate-Smart Framework. *For. Ecol. Manag.* **2008**, *256*, 313–327. [CrossRef]
37. He, P.; Wang, L.; Zhai, S.; Guo, Y.; Huang, J. Assessment of Landscape Risks and Ecological Security Patterns in the Tarim Basin, Xinjiang, China. *Land* **2025**, *14*, 1221. [CrossRef]
38. Xiong, H.; Hu, H.; Han, P.; Wang, M. Integrating Landscape Ecological Risks and Ecosystem Service Values into the Ecological Security Pattern Identification of Wuhan Urban Agglomeration. *Int. J. Environ. Res. Public Health* **2023**, *20*, 2792. [CrossRef] [PubMed]
39. O'Neill, R.V.; Krummel, J.R.; Gardner, R.H.; Sugihara, G.; Jackson, B.; DeAngelis, D.L.; Milne, B.T.; Turner, M.G.; Zygmunt, B.; Christensen, S.W.; et al. Indices of Landscape Pattern. *Landsc. Ecol.* **1988**, *1*, 153–162. [CrossRef]
40. Cumming, S.; Vervier, P. Statistical Models of Landscape Pattern Metrics, with Applications to Regional Scale Dynamic Forest Simulations. *Landsc. Ecol.* **2002**, *17*, 433–444. [CrossRef]
41. Lin, X.; Wang, Z. Landscape Ecological Risk Assessment and Its Driving Factors of Multi-Mountainous City. *Ecol. Indic.* **2023**, *146*, 109823. [CrossRef]
42. Gao, H.; Han, H.; Liu, Y.; Wang, T.; Bai, Y.; Ma, S.; Chen, S. Changes in landscape disturbance degree of steep slope land use in Guizhou Province from 1995 to 2015. *J. Nanjing For. Univ. (Nat. Sci. Ed.)* **2020**, *44*, 183–190. Available online: https://www.cabidigitallibrary.org/doi/full/10.5555/20220443903 (accessed on 23 October 2025).

43. Wang, Q.; Tang, F.; Li, Y.; Huang, J.; Bai, X. Spatio-temporal differentiation of landscape pattern evolution and its ecological security in karst areas: A case study of trough valley in northeast Guizhou Province. *Acta Ecol. Sin.* **2021**, *41*, 7273–7291. [CrossRef]
44. Wen, M.; Zhang, T.; Li, L.; Chen, L.; Hu, S.; Wang, J.; Liu, W.; Zhang, Y.; Yuan, L. Assessment of Land Ecological Security and Analysis of Influencing Factors in Chaohu Lake Basin, China from 1998–2018. *Sustainability* **2021**, *13*, 358. [CrossRef]

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