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Article

Landscape pattern changes in coal resource-based cities: A case study of Huainan City in China

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Abstract: Currently, coal resource-based cities (CRBCs) are facing challenges such as ecological destruction, resource exhaustion, and disordered urban development. By analyzing the landscape pattern, the understanding of urban land use can be clarified, and optimization strategies can be proposed for urban transformation and sustainable development. In this study, based on the interpretation of remote sensing data for three dates, the landscape pattern changes in the urban area of Huainan City, a typical coal resource-based city in Anhui Province, China were empirically investigated. The results indicate that: (1) There is a significant spatial-temporal transformation of land use, with construction land gradually replacing arable land as the dominant land use type in the region. (2) Landscape indices are helpful to reveal the characteristics of land transfer and distribution of human activities during a process. At the landscape type level, construction land, grassland, and water bodies are increasingly affected by human activities. At the landscape composition level, the number of landscape types increases, and the distribution of different types of patches becomes more balanced. In addition, to address the problems caused by the coal mining subsidence areas in Huainan city, three landscape pattern optimization strategies are proposed at both macro and micro levels. The research findings contribute to a better understanding of land use changes and their driving forces, and offer valuable alternatives for ecological environment optimization.

Keywords: landscape pattern; Huainan City; land use; dynamic change; coal resource-based city (CRBC)

1. Introduction

Coal resource-based cities (CRBCs) refer to cities that have emerged due to the development of the mining industry and are accompanied by urban construction and industrial changes resulting from coal resource exploitation. However, these cities face the risk of decline or even extinction due to resource depletion, or they may thrive and grow due to the expansion of non-mining or related industries (Tan et al., 2016). Many scholars have conducted extensive research on the industrial development, sustainable development and transformation, environmental protection and ecological governance, and spatial structure evolution of CRBCs (Yang et al., 2015). The analysis of landscape pattern changes and their driving forces has long been of continuous interest in the fields of ecology and geography. Based on remote sensing images of the urban area of Huainan City, this paper uses quantitative research methods to analyze the landscape pattern change and explore its driving factors, aiming to provide optimization strategies for landscape pattern optimization and sustainable urban transformation and development in the urban area of Huainan City.

Huainan City is located in the northern part of Anhui Province and is one of

China's important energy bases. It has abundant coal resources, with estimated reserves of 44.4 billion tons, accounting for 32% of the eastern region of China, and coalbed methane reserves of 592.8 billion cubic meters (Zhang and Gu, 2019). However, since the 1960s, the long-term coal mining in the region has caused ground subsidence (Zhang et al., 2023), which has affected a large number of urban areas and population throughout the city.

The research area of this study is the urban area of Huainan City, which includes five administrative districts: Datong, Tianjia'an, Xiejiaji, Bagongshan, and Panji. The city is located between 116°67′E and 117°21′E longitude, and 32°94′N and 32°38′N latitude, covering an approximate area of 1501.3961 km^2 (**Figure 1**). It is situated in a transitional zone between temperate and subtropical climates, with both hilly and plain terrains. There are abundant forest resources, including Shangya Forestry Farm and Bagongshan Forestry Farm. The area is also home to numerous rivers, lakes, and wetlands, represented by the Huai River, the Ni River, and the Wabu Lake. Huainan is a heavy industrial city built on the coal industry and energy development. The mining and utilization of coal in Huainan can be traced back to the 13th century, where people excavated soil pits and mined coal for heating and forging agricultural tools. In 1909, the Datong Coal Mining Company was founded, and in 1930, the Nationalist Government established the Huainan Coal Mining Bureau, leading to large-scale mining operations and the gradual development of the three major towns in Huainan: Tianjia'an, Datong, and Jiulonggang. However, during World War II in 1938, the coal resources in Huainan suffered from plundering and destruction. It was not until March 1949 that the Huainan coal mines resumed full operation. Since then, the Huainan coal mines have rapidly developed into an important coal production base (Yang et al., 2015). Starting from the 1960s, long-term coal mining has caused ground subsidence. Currently, the coal mining subsidence area in the region covers an area of 304.17 km^2, including a total of 27 towns. This has involved approximately 311,000 residents, accounting for 12.8% of the city's population (Zhang et al., 2023). The land subsidence caused by coal mining has had a severe impact on the rural economy of the city, especially in terms of agricultural production and the ecological environment. Farmers have lost their houses and farmland, leading to many households falling back into poverty and giving rise to numerous social issues. The Huainan municipal government has implemented a centralized relocation strategy for residents in the subsidence area, with several relocation sites planned throughout the city. As of now, the relocation of villages affected by coal mining subsidence in Huainan has been completed. Therefore, studying the changes in the landscape pattern of Huainan City is of great significance for optimizing the urban ecological security pattern, allocating urban construction, promoting urban industries, and achieving sustainable development.

Landscape pattern refers to the spatial arrangement of various landscape elements of different size and shape (Liu et al., 2010). Landscape pattern is composed of interacting ecosystems and spatial mosaics, which is the ultimate result of various natural and human factors acting at different spatiotemporal scales. The change in urban land use landscape pattern has become an important indicator of the tension level between the socio-economic system and the natural ecosystem (Braimoh, 2006; Zhang et al., 2006). To address the ecological and environmental issues brought about by urban land use change, it is necessary to explore and study the changes in landscape pattern and their driving forces in the process of urbanization.

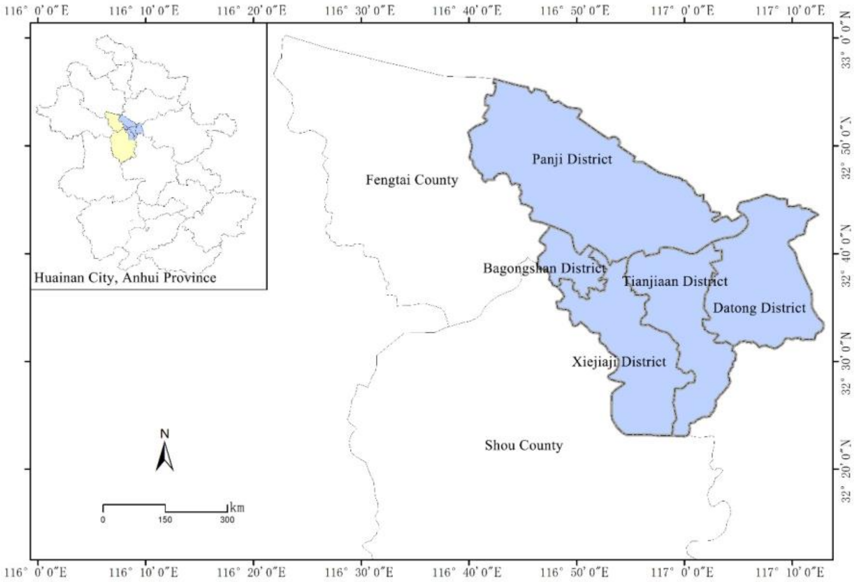

Figure 1. Scope of Huainan City in Anhui Province, China.

Scientific research has shown that land use change impacts landscape pattern (Hao et al., 2017). Scholars have mainly studied the characteristics of landscape pattern evolution through research on land transfer dynamics and landscape pattern indices. For example, Zhang et al. (Zhang et al., 2013), Fan and Myint (Fan and Myint, 2014), Ou et al. (Ou et al., 2004), Huang et al. (Huang et al., 2021), and Yang et al. (Yang et al., 2020) respectively studied the landscape patterns in the coastal zone of northern Jiangsu, Shandong coastal area, Dongting Lake area, Lancang River basin in China, and the hinterland mountainous area of the Three Gorges, and analyzed their driving forces. Weng (Weng, 2007) used the state of Wisconsin as an example and demonstrated through the study of landscape pattern change that land use diversity and fragmentation were positively correlated with the level of urbanization. Dadashpoor et al. (Dadashpoor et al., 2019) analyzed the impact of land use and urbanization on landscape pattern change in urban agglomerations, proving that there is a strong relationship between landscape pattern change and land use changes. Zhai et al. (Zhai et al., 2021) explored the land use structure of Wuhan city, used a land use simulation model to predict the dynamic development of future landscape pattern, and provided theoretical support for urban sustainable development.

The landscape pattern of CRBCs is influenced by coal mining and land use change, and usually undergoes a process of "exploitation-destruction-restoration-transformation". Coal mining can cause destruction of arable land, increase in water areas, and have a significant impact on the landscape, thus affecting land use and landscape pattern (Guan and Yu, 2021). Existing studies have proved the close correlation between land use change in CRBCs and their development, and the changing cycle of urban land exhibits a strong consistency with the coal life cycle (Li et al., 2013). The analysis of its driving factors can be regarded as a reflection of the socio-economic and development transformation of CRBCs (Wen et al., 2018). With the depletion of coal resources, urban landscapes need to transition from the original state of resource extraction and gradual restoration to new development models, posing new challenges for urban planning and policy development (Long et al., 2021). Example of coal seam gas extraction in Queensland shows that, the extensive development of unconventional resources has also caused great local landscape change (Bressan and Deshaies, 2023). This would give us insight that, mining activity initiated by both economic development demand and cleaner energy transition would impact considerably landscape form and pattern. However, the mechanism of landscape pattern evolution and their driving forces are yet not very clear. This study tries to analyze the characteristics of landscape pattern during the change periods with quaitative evaluation through a case study in CRBCs and provide a scientific basis for local sustainable land planning and ecological governance.

2. Methodology

The data used in this study includes Landsat-TM/ETM images from 2001 and 2011, as well as Landsat-8 OLI images from 2021. The images have a spatial resolution of 30 m × 30 m and consist of four spectral bands. These data can be obtained from the United States Geological Survey (USGS) website. (United States Geological Survey, 2022).

To preprocess the raw remote sensing images, radiometric calibration, atmospheric correction, image fusion, and cropping were performed using the software ENVI-Met. The study area was classified into five major categories: cultivated land, woodland, grassland, construction land, and water, using the Support Vector Machine (SVM) classifier. The overall classification accuracy and Kappa coefficient evaluation indicators are shown in **Table 1**, satisfying the accuracy standards for validation (Enoguanbhor et al., 2019). The final result is the spatial distribution characteristics of the landscape pattern in the study area, as shown in **Figure 2**.

Table 1. Overall accuracy and Kappa coefficient of land class extraction.

	2001	**2011**	**2021**
Overall classification accuracy	93.4127%	92.9524%	99.2734%
Kappa coefficient	0.9109	0.9052	0.9880

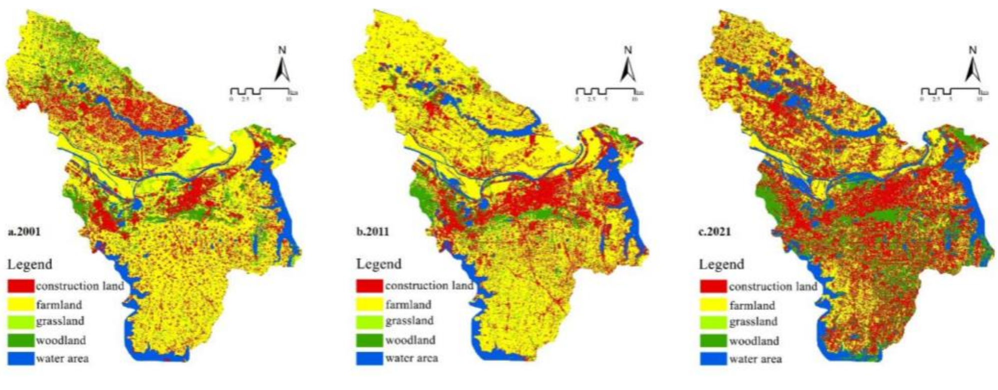

Figure 2. Land use changes in the Huainan Urban Area from 2001 to 2021.

The various land use types within the study area have interactive conversion relationships. This study is based on the land use transfer matrix (Liu et al., 2018) to investigate the conversions between different land use types. The mathematical formulation is represented as follows:

$$S_{ij}=\begin{bmatrix} S_{11} & \cdots & S_{1n} \\ \vdots & \vdots & \vdots \\ S_{n1} & \cdots & S_{nn} \end{bmatrix} \tag{1}$$

where S_{ij} represents the land use status at the beginning and end of the study period, n is the number of land use types. The vector represents the area of each land use type, reflecting the different landscape structures and their composition.

Additionally, spatial intersection analysis was performed using ArcGIS 10.6 on the land use maps of different periods to obtain land use type change maps within a shorter response time, enabling spatiotemporal analysis of land use changes.

Landscape pattern indices are highly generalized expressions of landscape pattern information that can reflect, to some extent, the composition and spatial configuration of landscapes (Zhao et al., 2021). These indices quantitatively describe the landscape pattern characteristics of a region (Saura and Martínez-Millán, 2000; Schumaker, 1996; Tischendorf, 2001). Based on existing research (Kong et al., 2007; Uuemaa et al., 2013) and considering the characteristics of the study area, seven indices were used at the landscape class level: Class Area (CA), Proportion of Landscape Occupied by a Class (PLAND), Number of Patches (NP), Patch Density (PD), Largest Patch Index (LPI), Perimeter-area Fractal Dimension (PAFRAC), and Aggregation Index (AI). Additionally, six indices were used at the landscape level: Landscape Shape Index (LSI), Aggregation Index (AI), Contagion Index (CONTAG), Division Index (DIVISION), and Shannon's Diversity Index (SHDI). The description of these indices can be found in the study of Schindler et al. (2008). The values of these indices were calculated using Fragstats 4.3 and Excel 2016.

For the studied period, a 10-year interval was chosen for the evaluation of land use transfer in Huainan City from 2001 to 2021. The first decade was a period of deteriorating ecological environment, while the following was a period of rapid urban development.

3. Results and analysis

3.1. Temporal change analysis

Calculation of the landscape pattern indices, including the Class Area (CA) and Proportion of Landscape Occupied by a Class (PLAND), at the landscape class level provides information on the changes in the area and proportion of different landscape classes in Huainan City for the years 2001, 2011, and 2021 (**Tables 2** and **3**).

Statistical data indicates significant changes in all land use types during the period from 2001 to 2021. From 2001 to 2011, cultivated land was the dominant landscape type in the Huainan City area, serving as the landscape matrix. However, there was still a decrease of 3.26% in cultivated land area. The largest decrease was observed in forest area, which decreased by 48.00%. Grassland, built-up area, and water bodies experienced an increase in their respective areas. Among them, grassland increased by 103.94 km^2, representing the highest increase among all classes. The built-up area increased by 17.63% in terms of area, and the water bodies increased by 5.28 km^2.

Table 2. Change of land cover types in the Huainan Urban Area from 2001 to 2011.

Land cover types	2001		2011		Change in area/km^2	Rate of change/%
	Area CA/km^2	Proportion PLAND/%	Area CA/km^2	Proportion PLAND/%		
Woodland	211.1248	14.1413	109.7922	7.2076	−101.3326	−47.9966
Grassland	30.4352	2.0129	134.3734	8.9354	103.9382	341.5059
Farmland	782.5370	51.9720	757.0281	50.3882	−25.5089	−3.2598
Construction land	334.4796	22.3003	352.1064	23.5341	17.6268	5.2699
Water area	142.8188	9.5734	148.0954	9.9348	5.2766	3.6946

Table 3. Change of land cover types in the Huainan Urban Area from 2011 to 2021.

Land cover types	2011		2021		Change in area/km^2	Rate of change/%
	Area CA/km^2	Proportion PLAND/%	Area CA/km^2	Proportion PLAND/%		
Woodland	109.7922	7.2076	256.1265	16.8713	146.3344	133.2831
Grassland	134.3734	8.9354	145.8971	9.5734	11.5237	8.5759
Farmland	757.0281	50.3882	337.5754	22.7690	−419.4526	−55.4078
Construction land	352.1064	23.5341	570.9985	37.9464	218.8922	62.1665
Water area	148.0954	9.9348	190.7979	12.8398	42.7025	28.8344

During the period from 2011 to 2021, there was a significant decrease in cultivated land, while other land use types showed an increase. Among them, the built-up area experienced the most significant growth, increasing by 218.89 km^2. The forest area returned to its level before 2011, with an increase of 146.33 km^2. The water bodies also expanded, with an increase of 42.70 km^2.

The land use transfer matrix can reflect the interconversion between different land use types. Based on Equation (1), the land use transfer matrices for the periods of 2001–2011, 2011–2021, and 2001–2021 in Huainan City were obtained. The land transfer in and out of each land use class can be seen in **Tables 4–6**, and a visual Sankey diagram (**Figure 3**) was generated.

Table 4. Land use cover dynamic transfer matrix in the Huainan Urban Area from 2001 to 2011.

2011	2001					
	Construction land	Farmland	Grassland	Water area	Woodland	Summation
Construction land	155.8447	125.5661	8.6394	15.5047	46.5515	352.1064
Farmland	119.9839	528.9020	13.8213	3.9760	90.3448	757.0280
Grassland	29.4767	79.7434	2.6247	1.0666	21.4621	134.3734
Water area	10.8072	10.1948	1.3566	119.6522	6.0847	148.0954
Woodland	18.3671	38.1308	3.9932	2.6194	46.6818	109.7922
Summation	334.4796	782.5370	30.4352	142.8188	211.1248	1501.3954

Table 5. Land use cover dynamic transfer matrix in the Huainan Urban Area from 2011 to 2021.

2021	**2011**					
	Construction land	**Farmland**	**Grassland**	**Water area**	**Woodland**	**Summation**
Construction land	214.7391	262.3758	55.8623	7.3956	30.6256	570.9985
Farmland	26.5019	285.2896	19.6626	0.8325	5.2889	337.5754
Grassland	30.8358	83.1091	20.2038	0.8193	10.9291	145.8971
Water area	23.6585	32.5277	4.8820	123.3338	6.3959	190.7979
Woodland	56.3710	93.7258	33.7627	15.7143	56.5527	256.1265
Summation	352.1064	757.0280	134.3734	148.0954	109.7922	1501.3954

Table 6. Land use cover dynamic transfer matrix in the Huainan Urban Area from 2001 to 2021.

2021	**2001**					
	Construction land	**Farmland**	**Grassland**	**Water area**	**Woodland**	**Summation**
Construction land	184.9216	296.8898	9.3824	4.9022	74.9024	570.9985
Farmland	60.6249	233.3523	4.4448	0.4725	38.6809	337.5754
Grassland	25.0696	96.2478	2.8296	0.5200	21.2302	145.8971
Water area	19.6323	36.6278	2.6016	117.0282	14.9079	190.7979
Woodland	44.2311	119.4192	11.1769	19.8959	61.4034	256.1265
Summation	334.4796	782.5370	30.4352	142.8188	211.1248	1501.3954

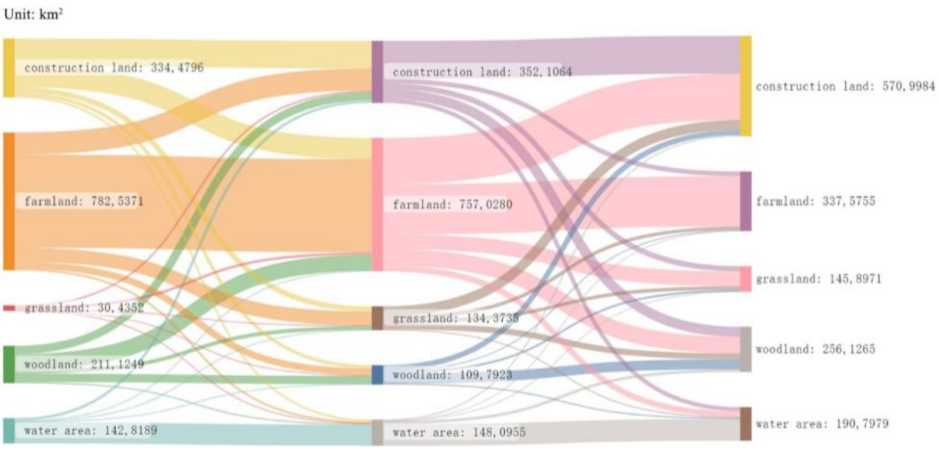

Figure 3. Sandkey map of land use transfer at different periods in the Huainan Urban Area from 2001 to 2021.

In terms of the changes in land area for different land types, cultivated land experienced the largest decrease. From 2001 to 2011, 125.57 km^2 of cultivated land was converted to built-up areas, and from 2011 to 2021, it further decreased by 262.38 km^2. Throughout the 20-year period, a total 190.80 km^2 of water area was converted from other land types. Among them, built-up areas received 19.63 km^2, and cultivated land received 36.63 km^2. The conversion was relatively intense from 2011 to 2021, which is closely related to subsidence in the coal mining subsidence areas. Cultivated land was the land type that mostly converted into built-up areas, with a total inflow of 296.89 km^2, reflecting the impact of urban development on agricultural land (Liu et al., 2014).

3.2. Spatial change analysis

From a spatial perspective (**Figure 4**), the inflow of water bodies is predominantly concentrated in the Bagongshan area, Panji district, and Datong district, closely integrated with the coal mining subsidence area. The outflow of built-up areas is more concentrated in the Panji district, which is also closely related to the coal mining subsidence area. The decrease in cultivated land is typical between 2011 to 2021 and is most pronounced in the Tianjia'an area and Xiejiaji district in the southern part of Shunfeng Mountain. It also shows a trend of multi-centered expansion.

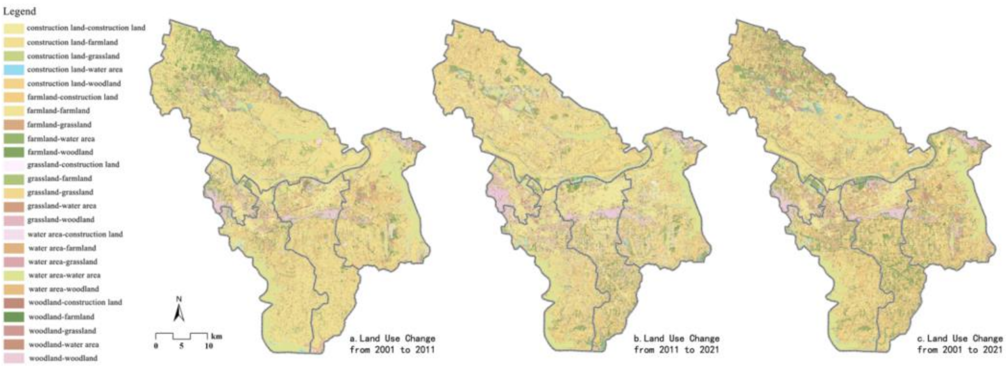

Figure 4. Spatial variations of land use change in the Huainan Urban Area from 2001 to 2021.

3.3. Analysis of landscape pattern indices changes at the landscape type level

As shown in **Table 7**, the Number of Patches (NP) and Patch Density (PD) of water bodies, grassland, and cultivated land continuously increased from 2001 to 2021. On the other hand, the NP and PD of built-up areas decreased continuously. The NP and PD of forest areas decreased from 2001 to 2011 and then increased from 2011 to 2021, ultimately recovering to the 2001 level. The Largest Patch Index (LPI) of built-up areas continued to increase, especially from 2011 to 2021, where it increased at a double speed. In contrast, the LPI of cultivated land and water bodies decreased, indicating that built-up areas were gradually expanding in a contiguous manner, while cultivated land and water bodies were gradually becoming fragmented. The Perimeter-area Fractal Dimension (PAFRAC) of built-up areas and grassland continued to increase and approached stability, indicating that landscape patches were more complex and influenced by human activities. The Aggregation Index (AI) of forest areas and built-up areas also increased continuously, indicating increasing connectivity between forest patches and built-up areas. On the other hand, the landscape AI of water bodies tended to be more dispersed but still remained at a relatively high level. As the coal mining subsidence continued, the area of water bodies increased, and the degree of fragmentation also increased.

Table 7. Landscape pattern index in the Huainan Urban Area from 2001 to 2021.

Land cover types	year	NP	PD	LPI	LSI	AREA_MN	PAFRAC	AI
	2001	1360	0.91	1.81	46.30	15.62	1.65	34.87
Woodland	2011	857	0.57	1.06	31.54	12.63	1.60	37.75
	2021	1364	0.91	1.19	47.76	18.57	1.64	38.56
	2001	422	0.28	0.12	21.96	7.16	1.61	17.49
Grassland	2011	1528	1.02	0.18	46.33	8.78	1.67	17.61
	2021	1840	1.23	0.07	49.65	7.81	1.67	14.60
	2001	370	0.25	26.89	43.49	210.94	1.65	68.37
Farmland	2011	439	0.29	25.39	40.10	172.37	1.63	70.42
	2021	761	0.51	3.33	42.46	44.93	1.62	53.21
	2001	1311	0.87	3.71	48.46	25.54	1.62	45.92
Construction land	2011	1303	0.87	8.63	48.27	27.12	1.65	47.54
	2021	778	0.52	18.68	54.76	73.25	1.67	53.20
	2001	219	0.15	2.54	17.69	65.65	1.53	70.70
Water area	2011	297	0.20	2.44	18.99	50.23	1.52	69.06
	2021	572	0.38	2.19	25.76	33.71	1.51	62.69

3.4. Analysis of landscape pattern indices changes at the landscape level

The landscape-level pattern index of Huainan City from 2001 to 2021 can be calculated using Fragstats to obtain landscape pattern indices (**Figure 5**). The Aggregation Index (AI) represents the degree of connectivity between patches. When there is no adjacency between patches, the value tends to be 0. When patches aggregate into a whole, the value is 100. The Contagion Index (CONTAG) represents the number of adjacent patches of different types, indicating the degree of aggregation between different patches. The Shannon's Diversity Index (SHDI) increases when the number of landscape types increases or when the distribution of different landscape components becomes more even. The value decreases when there are large differences in the proportions of different patches.

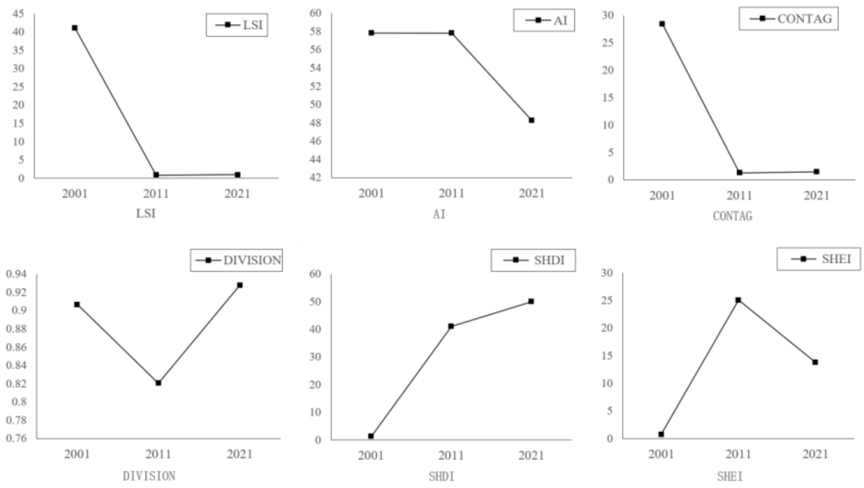

Figure 5. Landscape pattern index in the Huainan Urban Area from 2001 to 2021.

Overall, the landscape-level pattern index of this region has undergone varying degrees of change during different periods. The Landscape Shape Index (LSI) rapidly decreased from 2001 to 2011 and remained almost unchanged from 2011 to 2021, indicating a stagnation in the degree of landscape fragmentation during this period. The overall Shannon's Diversity Index (SHDI) of Huainan City gradually increased from 2001 to 2021, while the Contagion Index (CONTAG) and Aggregation Index (AI) gradually decreased. This indicates that the landscape pattern in Huainan City has become more complex, with patches becoming more fragmented and less aggregated, which is related to urban development and coal mining subsidence. The Division Index (DIVISION) decreased from 0.9067 in 2001 to 0.8205 in 2011 and then increased to 0.9277 in 2021. The trend of SHDI from 2001 to 2011 indicates an overall increase in landscape heterogeneity due to the increase in grassland and changes caused by coal mining. However, the trend reversed from 2011 to 2021.

4. Discussion

4.1. Analysis of driving factors of landscape pattern evolution in Huainan City

The landscape pattern in the urban area of Huainan City has been constantly changing against the background of urban development and coal mining subsidence. This study divides the changes in the landscape pattern in Huainan City into two periods: 2001–2011, which was a period of deteriorating ecological environment. Most of the mining areas were closed in the late 1970s and early 1980s. Due to long-term extensive use, coal mining subsidence continued to expand, leading to a trend of mutual conversion between grassland and cultivated land, and an increase in landscape diversity. This period also marked the beginning of urban development, with a small increase in built-up areas mainly converted from cultivated land and forest areas.

The period from 2011 to 2021 was a period of rapid urban development. The area of built-up land in the urban area of Huainan City, especially in the southern part of Shunfeng Mountain, increased substantially. This increase was mainly due to the conversion of cultivated land, grassland, and forest land. The direction of land development shifted towards artificial utilization. However, ecological restoration was also carried out during this period. The "returning cultivated land to forest" program resulted in an increase in forest area. The implementation of ecological restoration projects in the "Jiulonggang-Datong subsidence area" improved the ecological environment. Overall, the total area and density of grassland patches increased, and their connectivity improved, while the fragmentation of water bodies continued to increase.

Huainan is a typical CRBC, and the population, industrial structure, and coal production have a significant impact on the landscape pattern. Under the drive of projects such as the construction of development zones, urban renewal, and the launch of industrial areas, the urban area of Huainan has expanded rapidly, and the urban population has increased rapidly. In 2001, the permanent population of Huainan was 2.08 million, and it increased to 3.361 million in 2011, and 3.04 million in 2021. To meet the needs of population growth, a large amount of arable land has been converted into construction land, and this trend is increasing. Before 2015, the industrial structure of Huainan was dominated by the secondary industry, and the secondary industry showed a continuous growth trend. During the period from 2001 to 2011, the growth rate of the secondary industry in Huainan was the fastest, which had different degrees of impact on various geographic elements such as soil and vegetation, promoting the transformation of land cover and accelerating the change in landscape pattern. In 2011, the total output value of the secondary industry in Huainan began to decline. By 2015, the tertiary industry had taken the dominant position, and the industrial structure dominated by the secondary industry was changed. In 2020, Huainan closed 5 pairs of coal mines, but the adverse ecological effects caused by coal mining, such as vegetation destruction and soil quality decline, will not disappear in a short period of time (Yang et al., 2021).

The main drivers for the changes in the landscape pattern in the urban area of Huainan City are agriculture, forestry, and regional development policies, in addition to natural factors (changes in the coal mining subsidence area) (Zhang et al., 2019). Policy factors are important factors that guide the increase in large-scale construction space. Ecological land (forest land, cultivated land, grassland) and built-up land underwent changes under policy guidance. The government has issued various support policies for transformation, which can effectively improve the ecological restoration, water quality, and environmental conditions of resource-based mining areas (Yang et al., 2021). Currently, China has not yet established a sound legal system specifically for ecological restoration. The laws that guide the ecological restoration of coal mining subsidence areas mainly include the “Regulations on the Protection of Mine Geological Environment” and the “Guiding Opinions on Strengthening the Restoration and Integrated Management of Mine Geological Environment” (Li and Qin, 2013). These two documents provide detailed guidelines for the reclamation of coal mining subsidence channels. Anhui Province has formulated the “Management Measures for the Compilation and Management of the Plan for the Protection and Integrated Management of Mine Geological Environment in Anhui Province” and the “Regulations on the Protection of Mine Geological Environment in Anhui Province” (Gómez-Baggethun and Barton, 2013). The “Regulations on the Governance of Coal Mining Subsidence in Huainan City” provides legal basis for the geological environment restoration in the coal mining subsidence area (Hu, 2018). In addition, the resettlement of residents in the coal mining subsidence area in Huainan City is also an important reason for the transfer of built-up land (Li and Qin, 2013). The resettlement sites for residents who lost their land in the coal mining subsidence area are often located near the city center.

4.2. Optimization strategies for landscape pattern in Huainan City

Against the backdrop of coal mining subsidence, the ecological environment in Huainan City has suffered severe damage. Since the 1960s, extensive coal mining has led to extensive ground subsidence. The coal mining subsidence areas and their surrounding areas are facing significant development issues. The problems caused by the coal mining subsidence areas include the destruction of rural infrastructure and farmers’ houses, the impact on agricultural production, and the pollution of the ecological environment, leading to fragmentation of the ecological environment in the urban area and severe impacts on land use. Therefore, optimizing the urban planning pattern and ecological construction in the urban area of Huainan City has become an important issue that needs to be addressed (Guan and Yu, 2021). The followings are some of optimization strategies that can be adopted.

1) Promotion of the coordinated development of ecological space and other spaces. The focus of improving the ecological environment lies in balancing development and protection, strictly controlling development intensity, and not sacrificing the environment, such as forests, farmland, and water bodies, for development purposes (Cui et al., 2020). It is important to protect existing forest land, grassland, and water bodies, restore the ecological environment, restore ecosystem diversity, and enhance species richness and diversity. Strict control should be implemented on the development of forest land, water bodies, and farmland, while reasonably planning the construction land in the city to reduce scattered small patches. The productivity of farmland should be improved to enhance its quality and replace the quantity, providing support for urban construction, afforestation, the expansion of urban green spaces, and the construction of corridors.
2) The establishment of urban ecological corridor networks will reduce the fragmentation of land use, create concentrated land types, and increase the stability of regional ecosystems. Connecting fragmented water bodies formed by subsidence and enhancing connectivity between sources. In the Panji District, Bagongshan District, and Xiejiaji District, within the subsided coal mining area, the landscape pattern exhibits a distribution characterized by different-sized patches and scattered features. These patterns are centered around two inland mudflats, with the presence of lakes, reservoirs, ponds, and river channels of varied sizes (Fu et al., 2021). Ecological corridors can connect important ecological patches, providing not only an environment for urban biological migration and diffusion but also ventilation and public communication corridors for the city.
3) Additionally, it is necessary to optimize the layout of ecological zones and construction areas at a micro-level. In addition to preserving larger forest land and grassland within the city, it is also possible to create patches around natural vegetation and ecological corridors and connect them through the corridors. Green areas and micro-ecosystems can be created in these adjacent small patches to form a networked green structure and an urban ecosystem.

5. Conclusion

With the help of GIS Fragstats landscape analysis software and remote sensing images, this article qualitatively studied and analyzed the land use types, landscape transitions, and landscape pattern in Huainan City, a typical CRBC in China. Some general findings can be drawn as follows:

1) The spatiotemporal transformation of land use is evident. From 2001 to 2011, farmland was the dominant landscape type in the urban area of Huainan, occupying more than half of the total area. From 2011 to 2021, the area of

farmland significantly decreased, while the area of construction land increased substantially, driving by industrial zone development, infrastructure construction and urban renewal. The water areas and grassland consistently increased at different rates. According to the landscape transfer matrix analysis, a large portion of farmland was converted to construction land, while a smaller portion was converted to grassland, forest land, and water bodies. Construction land gradually replaced farmland as the predominant land use type in the region.

2) Landscape indices are helpful to reveal the characteristics of land transfer and distribution of human activities during a process. Based on the analysis of landscape pattern indices at the level of landscape types, the landscape shape indices of grassland, construction land, and water bodies increased, indicating increased human disturbance and greater complexity of patches. According to the analysis of landscape pattern indices at the landscape level, the Shannon diversity index continuously increased, indicating an increase in the variety of landscape types and a more even distribution of patch components.

In addition, to address the problems caused by the coal mining subsidence areas in Huainan city, three landscape pattern optimization strategies are proposed at both macro and micro levels. Landscape optimization should embody different development demands such as from ecological environment, local economy, public will and social equity.

6. Perspectives for further research

This study lacks quantitative research on the factors influencing landscape pattern and only provides qualitative analysis. In the future, it is hoped that a more comprehensive system for studying the driving factors of landscape pattern changes in CRBCs can be established. This system should consider ecological, economic, and cultural factors, and take into account the uniqueness of urban development, in order to propose suggestions for urban transformation and optimization.

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