Environment, Social and Governance; Vol.3, No.2; 2026
E-ISSN: 3006-3973 P-ISSN：3006-3965
DOI: https://doi.org/10.70267/ esg2026.v3n2.3244
Published by: Zeus Press

A Study on the Evolution of Land Use Diversity in Karst Mountainous Areas

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Abstract

Land is the foundation upon which human life depends, yet it is also a highly vulnerable ecological component within the ecological systems of karst mountain regions. Taking Huaxi District in Guiyang City as a case study, Based on an analysis of land use data for Huaxi District from 2005, 2010, 2015 and 2020, and utilising the spatial overlay analysis function in ArcGIS software, the study calculated the areas of land use types across these four periods and the land use transition matrices for three time segments, thereby analysing the evolution of land use in Huaxi District from 2005 to 2020. The results indicate that the evolution of land use diversity in Huaxi District was primarily characterised by the conversion of arable land and woodland. The land use diversity index showed an upward trend across all four time periods. While arable land and woodland remained the predominant land use types, their areas were decreasing, whilst the areas of urban and rural, industrial and mining, and residential land continued to increase. The dynamics of single land-use types exhibited significant changes, primarily manifested in the conversion of arable and forest land into urban and rural, industrial and mining, and residential land. The comprehensive land-use dynamics gradually increased, indicating that land use is undergoing dynamic changes. The land-use intensity index exceeded 200, placing it at an upper-middle level.

Keywords

Huaxi District, land use diversity, land use change, land use intensity

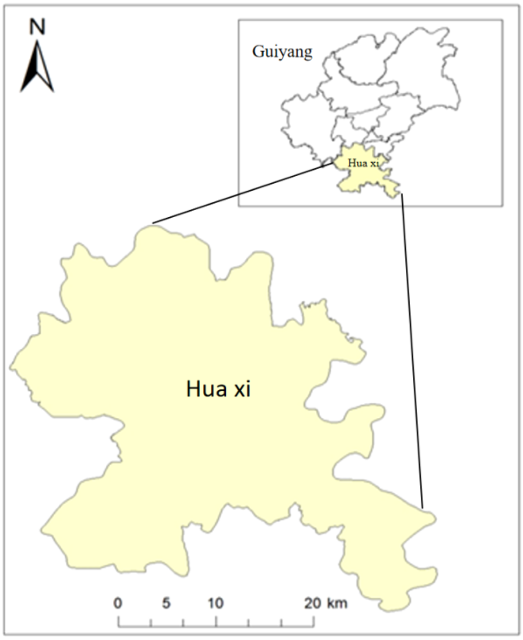
1. Introduction

Land resources are not only the most fundamental natural resources, but also the scarcest in karst mountain regions. How to maximise the utility of limited land resources to sustain economic growth has become a major land-related challenge facing humanity today. The rational utilisation of land resources not only conserves their quantity but also ensures their sustainable use. As the most vulnerable ecological factor in karst mountain regions, against this backdrop, numerous scholars have conducted extensive research in this field, examining land use in karst regions from various perspectives. For instance, Yang Xingyan employed a canonical correspondence analysis method to analyse the socio-economic factors underlying land use changes in the Guizhou-Guangxi karst region [1], whilst Zhao Yuluan utilised a land use conflict intensity model based on the ‘Pressure-State-Response (PSR)’framework to assess the evolution of land-use conflict intensity in the Guizhou-Guangxi karst regions from 1990 to 2010 [2]; Shao Jing’an studied land use in karst regions by examining the interrelationship between the underlying environment and land use [3]; Hou Yingyu utilised TM data to monitor urban land-use changes in karst regions [4]; Zhou Zeli guided by theories from landscape ecology, soil erosion principles and soil science, quantitatively analysed the spatio-temporal evolution of land use/land cover changes and soil erosion in karst regions, as well as the interrelationship between the two [5]; Gao Hongjuan proposed using the CLUE-S model to simulate land use changes in karst regions, reflecting future trends in land use within the study area [6]. These studies hold significant practical and research value in exploring the impact of specific factors on land use in karst mountain areas; however, research on the evolutionary process of land use in such regions remains limited. In light of this, this study selected Huaxi District as its research subject. Based on an overlay analysis of land use data from 2005, 2010, 2015 and 2020, and focusing on the evolution of land-use diversity, this study analyses changes in land-use category areas, land-use category flow patterns, land-use intensity, land-use dynamism, and changes in the land-use diversity index. This research holds significant importance for exploring land-use transformation and land-use conservation in Huaxi District.

2. Overview of the Research Area and Data Sources

Huaxi District, Guiyang City (106°27'–106°52' E, 26°11'–26°34' N) is situated in the central section of the Miao Ling Mountains on the Yungui Plateau, within the watershed between the Yangtze and Pearl River basins. It lies in the heart of Central Guizhou, to the south of Guiyang City, 12 km from the city centre, at an altitude of over 1,400 metres; the terrain is higher in the east and west and lower in the centre. 94% of the district's area comprises karst topography, making it a typical karst mountainous region. With a total land area of 963.26 km², mountains and hills constitute the district's primary landforms. Huaxi District has a forest coverage rate of 41.53% and has been designated a National Key Forest Conservation Project Area. The baseline data for this study was sourced from the Institute of Geographic Sciences and Natural Resources Research, Chinese Academy of Sciences (http://www.resdc.cn). The dataset is primarily based on remote sensing data from the US Landsat MSS, TM/ETM and Landsat 8 satellites, and was compiled using a human-computer interactive visual interpretation method. In accordance with the GLUCC classification system, land use types in the study area were categorised into five categories: cropland, forest land, grassland, water bodies, and urban and rural, industrial and mining, and residential land.

Figure 1: Study area diagram



2.1 Land Use Analysis

This study will use ArcGIS software to conduct an overlay analysis of land use data for Huaxi District from 2005, 2010, 2015 and 2020 to conduct a superimposition analysis. This will ultimately yield changes in the area of land use types and the proportion of each land use type relative to the total area of the study area. From this, the primary land use types in Huaxi District and the changes in the area of each land use category can be determined. Furthermore, the land use transition matrix can be used to identify the patterns of transition between different land use categories in Huaxi District, whilst calculating the land use dynamism index will reveal the rate and magnitude of change in the area of land use types in Huaxi District. calculating the land use intensity reveals the extent to which land use types in Huaxi District are influenced by human and natural factors; and calculating the land use diversity index provides an understanding of the variety of land use types and the complexity of land use in Huaxi District. Based on this research, the direction of evolution, dynamic changes and intensity of land use diversity in Huaxi District across different time periods can be determined, thereby enabling the formulation of appropriate optimisation proposals to address shortcomings identified in the evolution of land use diversity in Huaxi District.

2.2 Rate of Land-use Change

Land use dynamism describes the rate of change in land use within a study area [7]. It is defined as the variation in the number of land use types within a study area over a specific time period [8], and plays a crucial role in comparing spatial differences in land use change [9]. Generally, the dynamism of a single land use type is used to describe the rate and magnitude of change in the area of that land use class within a study area over a given time period. The formula for the dynamism of a single land use type is:

$$M = \frac{U_b - U_a}{U_a} \times \frac{1}{T} \times 100\% \qquad M_t = \frac{U_b - U_a}{U_a} \times 100\% \tag{1}$$

In Equation (1), M represents the dynamic rate of a specific land use category within the study area; U_a and U_b denote the areas of a given land use category at the start and end of the study period, respectively; and T represents the duration of the study period. When T is set to years, Mt represents the annual rate of change in land use.

The composite land use dynamic rate describes the pace of land use change in the region and is expressed by the following formula:

$$L_c = \left(\frac{\sum_{i=1}^{n} \Delta L_{i-u}}{2\sum_{i=1}^{n} \Delta L_{u_i}}\right) \times \frac{1}{T} \times 100\% \tag{2}$$

In Equation (2), L_c represents the comprehensive land use dynamism index, the magnitude of which indicates the intensity of land use change in the region [10]; L_{u_i} denotes the area of land use type i at the start of the study period; ΔL_{i-u} is the absolute value of the area of land use type i converted to land use type j during a given time period; and T denotes the time period.

2.3 Changes in Land Use Intensity

The degree of land use primarily describes the extent of land use from both temporal and spatial perspectives, highlighting the influence of natural and human factors on land types [11]. The calculation formula is as follows:

$$Sa = 100 \times \sum_{i}^{n} C_i \times D_i \tag{3}$$

In Equation (3),Sa represents the comprehensive land use index, with a range of [100, 400]; Ci denotes the proportion of land use type i; and Di denotes the weighting index for the corresponding land use category. Drawing on the research findings of Liu Jiyuan regarding land use intensity [12], land use types are classified into four categories, with the corresponding weighting indices shown in Table 1.

Table 1: Index of land use degree

Primary land category	Secondary land category	Land type assignment
Township and settlement land grade	towns, residential areas, industrial and mining land, transportation land	4
agricultural land grade	arable land, orchards	3
forest, grassland, water body land grade	wooded area, grassland, water body	2
unutilized land grade	unutilized and hard-to-utilize land	1

2.4 Land Use Diversity Index

The land use diversity index quantifies the complexity of land use patterns in a study area over a specific period, reflecting the variety of land use types within that timeframe [13]. The calculation formula is as follows:

$$A = -\sum_{i=1}^{n}[h_i * ln(h_i)] \quad (4)$$

In Equation (4), the value of A represents the land use diversity index; A is positively correlated with changes in the area of land use categories and the land use structure. n denotes the number of land use categories, and h_i denotes the proportion of the area occupied by the i-th land use category within the entire study area.

3. Results and Analysis

3.1 Analysis of the Current Status of Land Use in Huaxi District

The current land use maps for Huaxi District for 2005 and 2010 are shown in Figure 2. The proportions of land use types are shown in Table 2, and the areas of each land use type are shown in Table 3. The information presented in the following charts and tables reveals the characteristics of land use changes in Huaxi District.

Figure 2: Map of land use types in Huaxi District

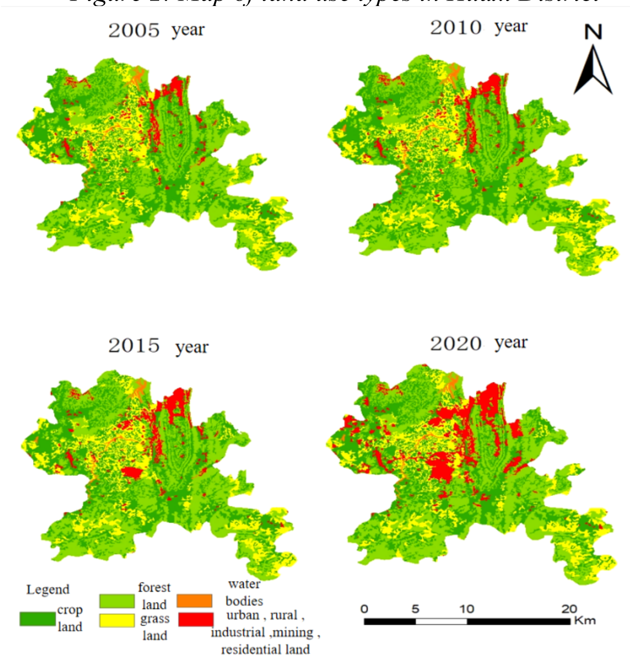


Table 2: Area proportion of different land types in Huaxi District from 2005 to 2020

Year/Category	Plough	Forest land	Meadow	Waters	Urban and rural land, industrial and mining land, residential land
2005	39%	40%	16%	1%	4%
2010	39%	39%	17%	1%	4%
2015	38%	39%	16%	1%	6%
2020	35%	38%	15%	1%	11%

Table 3: Area of land use types in Huaxi District from 2005 to 2010

Land use type	Area (km²)		Area change (km²)
	2005	2010	
plough	374.58	372.02	-2.57
forest land	384.23	379.50	-4.73
meadow	154.26	159.29	5.03
waters	9.40	9.40	0.00
urban and rural land, industrial and mining land, residential land	40.80	43.06	2.26

As can be seen from Tables 2 and 3, the main land categories in Huaxi District in 2005 were arable land, woodland and grassland, accounting for 39%, 40% and 16% of the total area respectively, whilst the area of water bodies remained unchanged. The land use diversity index rose from 1.20 to 1.21 between 2005 and 2010, indicating that the complexity of Huaxi District's land use structure increased during this period, with a slight upward trend in the variety of land use types. In 2010, the primary land use types remained arable land, woodland and grassland, accounting for 39%, 39% and 17% of the total land area respectively. The dynamic changes in the structure of land use types are characterised as follows:

1) The area of arable land decreased slightly, falling from 374.58 km² in 2005 to 372.02 km² in 2010, a change of 2.57 km².
2) The area of woodland also decreased, falling from 384.23 km² in 2005 to 379.50 km² in 2010, a reduction of 4.73 km².
3) The area of grassland increased, rising from 154.26 km² in 2005 to 159.29 km² in 2010, representing an increase of 5.03 km² and a growth rate of 1%.
4) The area of water bodies remained unchanged; the water area was consistent at 9.40 km² in both 2005 and 2010, with no change in area.
5) There was a slight change in the area of urban, industrial, mining and residential land. In 2005, the total area of urban, industrial, mining and residential land was 40.80 km², and by 2010, this had increased to 43.06 km², representing a change of 2.26 km².

3.2 Quantitative Analysis of Land Use Changes in Huaxi District in 2010 and 2015

Table 4: Area of land use types in Huaxi District from 2010 to 2015

Land use type	Area (km²)		Area change (km²)
	2010	2015	
plough	372.02	362.39	-9.62
forest land	379.50	376.91	-2.59
meadow	159.29	157.22	-2.07
waters	9.40	9.39	-0.01
urban and rural land, industrial and mining land, residential land	43.06	57.35	14.29

The current land use maps for the entire study area for 2010 and 2015 are shown in Figure 2. The proportions of land use types are shown in Table 2, and the areas of land use types are shown in Table 4. It can be seen from Tables 2 and 4 that the main land categories in Huaxi District in 2015 were arable land, woodland and grassland, accounting for 39%, 40% and 16% of the total land area respectively. During this period, the land use diversity index rose from 1.21 in 2010 to 1.24 in 2015, indicating that the complexity of Huaxi District's land use structure increased, with a slight upward trend in the variety of land use types. Based on the information presented in the charts, the dynamic characteristics of the land use structure in Huaxi District can be summarised as follows:

1) A slight decrease in arable land area: the area of arable land decreased from 372.02 km² in 2010 to 362.39 km² in 2015, representing a reduction of 9.62 km² and a decrease of 1%.
2) The area of woodland has also decreased, falling from 379.50 km² in 2010 to 376.91 km² in 2015, a reduction of 2.59 km².
3) The area of grassland decreased slightly, falling from 159.29 km² in 2010 to 157.22 km² in 2015, a reduction of 2.07 km².
4) The change in the area of water bodies was negligible, decreasing from 9.40 km² in 2010 to 9.39 km² in 2015, a reduction of 0.01 km².
5) The area of land designated for urban and rural, industrial and mining, and residential use showed a significant increase. The total area of this land category was 43.06 km² in 2010, rising to 57.35 km² by 2015, representing an increase of 14.29 km².

3.3 Quantitative Analysis of Land Use Changes in Huaxi District in 2015 and 2020

Table 5: Area of land use types in Huaxi District from 2015 to 2020

Land use type	Area (km²)		Area change (km²)
	2015	2020	
plough	362.39	332.06	-30.34
forest land	376.91	368.42	-8.50
meadow	157.22	143.24	-13.98
waters	9.39	9.70	0.31
urban and rural land, industrial and mining land, residential land	57.35	109.86	52.50

The current land use maps for Huaxi District for 2015 and 2020 are shown in Figure 2. The proportions of land use types are shown in Table 2, and the areas of each land use type are shown in Table 5. From Tables 2 and 5, it can be seen that the main land categories in Huaxi District in 2020 were arable land, woodland, grassland, urban and rural areas, industrial and mining areas, and residential land, with the respective proportions of land area for each category being 35%, 38%, 15% and 11%. During this period, the land use diversity index rose from 1.24 in 2015 to 1.31 in 2020, marking the most significant change in the land use diversity index across the entire study period. This indicates that land use diversity in Huaxi District evolved rapidly during this period, the complexity of the land use structure increased, and there were substantial changes in the types of land use. The dynamic characteristics of the land use structure are as follows:

1) The area of arable land has continued to decrease, falling from 362.39 km² in 2015 to 332.06 km² in 2020, a reduction of 30.34 km² or 3%.

2) The area of forest land has also decreased, falling from 376.91 km² in 2015 to 368.42 km² in 2020, a reduction of 8.50 km² or 1%.

3) The area of grassland also decreased slightly, falling from 157.22 km² in 2015 to 143.24 km² in 2020, a reduction of 13.98 km² and a decrease of 1%.

4) The area of water bodies increased slightly, rising from 9.39 km² in 2015 to 9.70 km² in 2020, an increase of 0.31 km².

5) The area of urban and rural, industrial and mining, and residential land saw a significant increase compared to the previous period, rising from 57.35 km² in 2015 to 109.86 km² in 2020, representing an increase of 52.50 km².

3.4 Analysis of the Characteristics of Changes in Land Use Types in Huaxi District

Land use transition matrices describe the transformations between various land use types [14]; they not only reflect the relationships between the areas of different land use categories but also illustrate changes in these categories over different time periods [15], thereby facilitating an understanding of the sources and sinks of each land use type during the study period [16]. With the support of ArcGIS software, the land use vector maps for the four periods were overlaid to generate land use transition matrices for the three time periods: 2005–2010, 2010–2015 and 2015–2020. These play a significant role in analysing the evolution of land use diversity, as they can accurately reflect the interconversion relationships between different land use categories, thereby providing insight into the structural characteristics of various land types before and after the transition [15].

Based on the land use transition matrix, this study analyses changes in the area of land use categories in Huaxi District across three periods: 2005–2010, 2010–2015 and 2015–2020. This analysis provides insights into the flow of land use categories out of and into Huaxi District over the 15-year period, as well as information on the transitions between different land use categories within the same timeframes.

Tables 6 and 7 illustrate the changes in the area of land use types in the study area between 2005 and 2010. During this period, the area of four land categories underwent changes, with a total change of 7.73 km². The area of other land categories converted to arable land was 0.00 km², whilst the area of arable land converted to other land categories was 2.57 km², primarily shifting to forest land, grassland, urban and rural areas, industrial and mining areas, and residential land, with conversion areas of 0.35 km², 0.21 km² and 2.01 km² respectively; the total area of arable land decreased by 2.57 km²; The area of other land categories converted to forest land was 0.35 km², whilst the area of forest land converted to other land categories was 5.08 km², primarily to grassland, urban and rural areas, industrial and mining sites, and residential land, with conversion areas of 4.90 km² and 0.18 km² respectively; the total area of this land category decreased by 4.93 km²; The area of other land categories converted to grassland was 5.11 km², whilst the area of grassland converted to other land categories was 0.08 km², primarily to urban and rural, industrial and mining, and residential uses; the conversion area was 0.08 km², resulting in an increase of 5.03 km² in the total area of these land categories; The area of water bodies flowing into and out of other land categories was 0.00 km²; the area of other land categories flowing into urban, industrial, mining and residential land was 2.27 km², whilst the area of urban, industrial, mining and residential land flowing into other land categories was 0.00 km², resulting in an increase of 2.27 km² in the total area of these land categories.

Table 6: Land use transfer matrix of Huaxi District from 2005 to 2010(Unit: km²)

Land use types in 2005	Land use types in 2010					Amount to
	plough	forest land	meadow	waters	urban and rural land, industrial and mining land, residential land	
plough	372.01	0.35	0.21		2.01	374.58
forest land	0.00	379.15	4.90		0.18	384.23
meadow			154.18		0.08	154.26
waters				9.40		9.40
urban and rural land, industrial and mining land, residential land		0.00			40.80	40.80
amount to	372.02	379.50	159.29	9.40	43.06	963.26

Table 7: Statistical analysis of land type area changes in Huaxi District (2005-2010)(Unit: km²)

Land use type	Inflow	Outflow	Variable quantity
plough	0.00	2.57	-2.57
forest land	0.35	5.08	-4.93
meadow	5.11	0.08	5.03
waters	0.00	0.00	0.00
urban and rural land, industrial and mining land, residential land	2.27	0.00	2.27
amount to	7.73	7.73	-

Table 8: Land use transfer matrix of Huaxi District (2010-2015) (unit: km²)

Land use types in 2010	Land use types in 2015					Amount to
	plough	forest land	meadow	waters	urban and rural land, industrial and mining land, residential land	
plough	350.87	7.00	3.73	0.11	10.19	371.90
forest land	6.78	367.53	1.53	0.12	3.37	379.33
meadow	3.97	1.40	151.42	0.17	2.27	159.23
waters	0.10	0.15	0.15	8.98	0.00	9.39
urban and rural land, industrial and mining land, residential land	0.58	0.63	0.31	0.00	41.51	43.04
amount to	362.31	376.71	157.14	9.39	57.34	962.88

Table 9: Statistical analysis of land type area changes (2010-2015) (Unit: km²)

Land use type	Inflow	Outflow	Variable quantity
plough	11.43	21.03	-9.60
forest land	9.18	11.80	-2.62
meadow	5.72	7.81	-2.09
waters	0.40	0.40	0.00
urban and rural land, industrial and mining land, residential land	15.83	1.52	14.31
amount to	42.56	42.56	-

Tables 8 and 9 illustrate the changes in the area of land use types in the study area between 2010 and 2015. During this period, the area of all five land categories underwent changes, with a total change of 42.56 km². The area converted from other land categories to arable land was 11.43 km², whilst the area converted from arable land to other categories was 21.03 km², primarily shifting to forest land, grassland, water bodies, urban and rural areas, industrial and mining areas, and residential land, with conversion areas of 7.00 km², 3.73 km², 0.11 km² and 10.19 km² respectively; the total area of these categories decreased by 9.60 km²; The area of other land categories converted to forest land was 9.18 km², whilst the area of forest land converted to other land categories was 11.80 km², primarily to arable land, grassland, water bodies, urban and rural areas, industrial and mining areas, and residential land, with conversion areas of 6.78 km², 1.53 km², 0.12 km² and 3.37 km² respectively; the total area of forest land decreased by 2.62 km²; The area of other land categories converted to grassland was 5.72 km², whilst the area of grassland converted to other land categories was 7.81 km², primarily to arable land, forest land, water bodies, urban and rural areas, industrial and mining areas, and residential use, with conversion areas of 3.97 km², 1.40 km², 0.17 km² and 2.27 km² respectively; the total area of this land category decreased by 2.09 km²; The area flowing into and out of water bodies was 0.40 km² in both cases; the outflow was mainly converted into arable land, woodland and grassland, with conversion areas of 0.10 km², 0.15 km² and 0.15 km² respectively; the area flowing from other land categories into urban and rural, industrial and mining, and residential land was 15.83 km²; the area transferred from urban, industrial, mining and residential land to other land categories was 1.52 km², primarily flowing into arable land, woodland and grassland, with conversion areas of 0.58 km², 0.63 km² and 0.31 km² respectively; the total area of these land categories increased by 14.31 km².

Table 10: Land use transfer matrix of Huaxi District (2015-2020) (unit: km²)

Land use types in 2015	Land use types in 2020					Amount to
	plough	forest land	meadow	waters	urban and rural land, industrial and mining land, residential land	
plough	318.94	8.02	3.96	0.41	31.07	362.39
forest land	8.23	358.32	1.00	0.17	9.20	376.91
meadow	4.13	1.04	137.81	0.38	13.85	157.22
waters	0.33	0.15	0.19	8.72	0.00	9.39
urban and rural land, industrial and mining land, residential land	0.44	0.87	0.28	0.02	55.73	57.35
amount to	332.06	368.42	143.24	9.70	109.86	963.26

Table 11: Statistical analysis of area changes of land use types (2015-2020) (Unit: km²)

Land use type	Inflow	Outflow	Variable quantity
plough	13.13	43.46	-30.33
forest land	10.08	18.60	8.52-
meadow	5.43	19.40	-13.97
waters	0.98	0.67	0.31
urban and rural land, industrial and mining land, residential land	53.85	1.61	52.24
amount to	83.47	83.74	-

Tables 10 and 11 illustrate the changes in the area of land use types in the study area between 2015 and 2020. During this period, the area of all five land categories underwent changes, with a total change of 83.47 km², representing a significant increase compared to the previous two periods. The area converted from other land categories to arable land was 13.13 km², whilst the area converted from arable land to other categories was 43.46 km², primarily shifting to forest land, grassland, water bodies, urban and rural areas, industrial and mining areas, and residential land, with conversion areas of 8.02 km², 3.96 km², 0.41 km² and 31.07 km² respectively; the total area of arable land decreased by 30.33 km². The area of other land categories converted to woodland was 10.08 km², whilst the area of woodland converted to other land categories was 18.60 km², primarily to arable land, grassland, water bodies, urban and rural areas, industrial and mining sites, and residential land, with conversion areas of 8.23 km², 1.00 km², 0.17 km² and 9.20 km² respectively; the total area of this land category increased by 8.52 km²; The area of other land categories converted to grassland was 5.43 km², whilst the area of grassland converted to other land categories was 19.40 km², primarily to arable land, forest land, water bodies, urban and rural areas, industrial and mining areas, and residential use, with conversion areas of 4.13 km², 1.04 km², 0.38 km² and 13.85 km² respectively; the total area of this land category decreased by 13.97 km²; The area of other land categories converted to water bodies was 0.98 km², whilst the area of water bodies converted to other land categories was 0.67 km². The converted areas were primarily transformed into arable land, woodland and grassland, with conversion areas of 0.33 km², 0.15 km² and 0.19 km² respectively; the total area of these land categories increased by 0.31 km²; The area of other land categories flowing into urban and rural, industrial and mining, and residential land was 83.47 km², whilst the area of urban and rural, industrial and mining, and residential land flowing into other land categories was 1.61 km². This flow was primarily directed towards arable land, woodland and grassland, with conversion areas of 0.44 km², 0.87 km² and 0.28 km² respectively, resulting in an increase in land category area of 57.35 km².

3.5 Analysis of Changes in Land Use Extent and Rate

Using Equations (1) and (2), it is possible to calculate the single land-use dynamics and comprehensive land-use dynamics for Huaxi District for the periods 2005–2010, 2010–2015 and 2015–2020.

Table 12: Land use dynamic rate of Huaxi District (%)

Land use type	$M_{t2005-2010}$	$L_{c2005-2010}$	$M_{t2010-2015}$	$L_{c2005-2010}$	$M_{t2015-2020}$	$L_{c2015-2020}$
plough	-0.69		-9.62		-8.37	
forest land	-1.23		-2.59		-2.26	
meadow	3.26	0.13	-2.07	0.25	-8.89	0.93
waters	0.00		-0.01		3.30	
urban and rural land, industrial and mining land, residential land	5.54		14.29		91.54	

As shown in Table 12, between 2005 and 2010, the land use dynamics for arable land and forest land were negative, at -0.69% and -1.23% respectively, whilst those for grassland and urban, industrial, mining and residential land were positive, at 3.26% and 5.54% respectively. whilst the land use dynamics for water bodies was 0, indicating that the area of water bodies remained unchanged during this period. Between 2010 and 2015, the land use dynamics for arable land, forest land, grassland and water bodies were negative, with values of -9.62%, -2.59%, 2.07% and 0.01% respectively, the land use dynamics for urban and rural, industrial and mining, and residential land were positive, with values of 14.29%. From 2015 to 2020, the land use dynamics for arable land, forest land and grassland were negative, with values of -8.37%, -2.26% and -8.89% respectively. The land use dynamics for water bodies, urban and rural areas, industrial and mining areas, and residential land were positive, with values of 3.30% and 91.54% respectively. The land use dynamics for arable land and forest land were both less than 0 across the three periods, indicating that the area converted out of these land types exceeded the area converted into them during these periods. The changes in the dynamics of urban and rural, industrial and mining, and residential land were the most significant, with a maximum value of 91.54%. This increase was far greater than that of other land categories, indicating that, with rapid economic development, the demand for urban and rural, industrial and mining, and residential land has consequently increased. Table 4-7 shows that the comprehensive land use dynamics for Huaxi District during the three periods of 2005–2010, 2010–2015 and 2015–2020 were 0.13%, 0.25% and 0.93% respectively. From these figures, it can be seen that the comprehensive land use dynamism was highest during the 2015–2020 period, at 0.93%. This indicates that the greatest changes in the number of land use types occurred during this period 16, with the turnover of land types far exceeding that of the other two periods. This suggests that human activity was more intense during this period, indicating that Huaxi District's overall development progressed rapidly between 2015 and 2020, effectively promoting the district's economic and social development [17]. It also indicates that land utilisation efficiency in Huaxi District was improving during this phase, thereby driving industrial and urbanisation development [18].

Using Equation (3) and the data on the proportions of land use types in Huaxi District, the comprehensive land use index for Huaxi District in 2005, 2010, 2015 and 2020 can be calculated, as shown in Table 13 [19].

Table 13: Huaxi District land use comprehensive degree index

Time	2005	2010	2015	2020
land use comprehensive index	247	247	250	257

Table 13 shows that the level of land utilisation in Huaxi District remained at an upper-middle level throughout the study period, though there was still room for improvement relative to the maximum value of 400. During the study period from 2010 to 2020, this figure rose gradually, reaching a maximum of 257. This indicates that land utilisation in Huaxi District during this period was relatively comprehensive, with a high degree of utilisation and an upper-middle level of land use intensity, whilst the socio-economic sector was in a phase of upward development.

3.6 Land Use Diversity Index

Using Equation (4) and the proportions of land use types in Huaxi District shown in Table 2, the land use diversity index for Huaxi District for the period 2005–2020 can be calculated, as shown in Table 14.

Table 14: Land use diversity index of Huaxi District from 2005 to 2020

A particular year	2005	2010	2015	2015
land use diversity index	1.20	1.21	1.24	1.31

Table 14 shows that the Land Use Diversity Index for Huaxi District in 2005, 2010, 2015, 2020 were 1.20, 1.21, 1.24 and 1.31 respectively. These values rose gradually over the study period, increasing from 1.20 in 2005 to 1.31 in 2020, indicating that land use diversity in Huaxi District underwent a diversification process during the study period, with mutual conversions occurring between various land categories such as arable land, woodland, grassland, water bodies, urban and rural areas, industrial and mining land, and residential land. Notably, between 2005 and 2010, the Land Use Diversity Index rose from 1.20 in 2005 to 1.21 in 2010, an increase of 0.01. This was primarily due to only minor changes in the areas of arable land and forest land during this period, whilst the areas of other land use types remained virtually unchanged. From 2010 to 2015, the land use diversity index rose from 1.21 in 2010 to 1.24 in 2015, an increase of 0.03. During this period, the areas of arable land, woodland and grassland all underwent changes, but the magnitude of these changes was less than 10 km²; consequently, the land use diversity index for this period differed little from that of the previous period. From 2015 to 2020, the Land Use Diversity Index rose from 1.24 in 2015 to 1.31 in 2020, an increase of 0.07. Compared with the previous two periods, this represents a significant change in value, primarily due to shifts in the areas of arable land, woodland, grassland, water bodies, urban and rural areas, industrial and mining land, and residential land. In particular, the changes in the areas of arable land, grassland, urban and rural areas, industrial and mining areas, and residential land. Viewed across the entire study period, the Land Use Diversity Index has been in a state of constant fluctuation, indicating that the complexity of land use and the variety of land use types in Huaxi District have been undergoing dynamic evolution throughout the study period, with the number of evolving land categories also continuing to increase.

4. Discussion

Land is an essential resource upon which human survival depends; consequently, research into the evolution of land-use diversity forms a crucial foundation for ensuring the full utilisation of land resources. The conclusions drawn from this study on the evolution of land-use diversity in Huaxi District are broadly consistent with the land-use types observed in the district during the study period.

(1) The proportion of arable land in the land use area remained unchanged between 2005 and 2010, but there were varying degrees of reduction in area during the corresponding period from 2010 to 2020. The area of woodland showed relatively little change across the three periods, decreasing from 40% in 2005 to 38% in 2020. The area of grassland decreased only slightly across the corresponding periods, falling from 16% in 2005 to 15% in 2020, a reduction of 1 percentage point. The area of water bodies did not undergo any significant change throughout the entire study period, with their proportion remaining at approximately 1% throughout. The proportion of land allocated to urban and rural, industrial and mining, and residential use underwent significant changes. Between 2005 and 2010, the proportion of land allocated to these uses remained at 4%, showing no change during this period. Between 2010 and 2015, the proportion of land allocated to urban and rural, industrial and mining, and residential use increased from 4% in 2010 to 6% in 2015, representing an increase of 2 percentage points. Between 2015 and 2020, the proportion of land area occupied by urban, industrial, mining and residential land increased from 6% in 2015 to 11% in 2020, representing a 5% increase. The primary reason for this is that Huaxi District has accelerated the advancement of urbanisation, leading to an increase in the area of urban, industrial, mining and residential land. However, whilst the economy is developing rapidly, greater emphasis must be placed on the protection of arable and forest land, and strict land-use plans must be formulated to ensure a balanced relationship between development and the rational use of land.

(2) Both the single land use dynamism index and the comprehensive land use dynamism index are on the rise, indicating that the diversity of land use in Huaxi District is evolving in each period. The increase in both the comprehensive land use index and the land use diversity index suggests that the level of land use in Huaxi District was high during the study period and that the number of evolving land use types is increasing. This outcome is attributable to the support of policies implemented in Huaxi District during this period, including the strengthening of spatial optimisation and land-use control, as well as the promotion of land conservation and intensive use.

(3) Based on a superimposed analysis, this study quantified changes in the area of land use types in Huaxi District and the proportion of each land use category. A land use transition matrix was compiled to identify shifts between categories, and corresponding indicator values were calculated. This enabled the identification of the direction of evolution in land use diversity within Huaxi District, providing a reference for the adjustment of land use types in the district.

However, due to data limitations during the research process, this paper did not examine the land use diversity of the townships under Huaxi District's jurisdiction; the study focused solely on first-level land use categories. Secondly, this study lacks an examination of the driving factors behind the evolution of land use in Huaxi District, resulting in a lack of insight into the causes of land use evolution and the inability to predict future land use trends in the study area. Consequently, further exploration of the evolution of land use diversity at the township level is of particular importance.

5. Conclusion

Based on land use data from Huaxi District for the years 2005, 2010, 2015 and 2020, this paper examines the current status of land use, spatiotemporal changes, dynamics and intensity of land use in Huaxi District. It analyses the evolution of land use diversity in the district and draws the following conclusions.

(1) Land use diversity in Huaxi District underwent dynamic evolution during the study period. Both the complexity and the variety of the land use structure underwent relatively distinct changes, primarily manifested in a significant increase in the areas of urban and rural, industrial and mining, and residential land, alongside a substantial reduction in arable land and a slight decrease in grassland and woodland. However, the changes in land use structure varied across different periods.

(2) Between 2005 and 2020, land use in Huaxi District was predominantly characterised by arable land, woodland and grassland, with these three land categories accounting for over 80% of the total area. However, the most significant changes in area occurred in arable land and woodland, which continued to decrease throughout the study period, with the lost area primarily being reallocated to urban and rural, industrial and mining, and residential land. The area of urban, industrial, mining and residential land rose from 40.80 km² in 2005 to 109.86 km² in 2020, indicating that the pace of urbanisation in Huaxi District accelerated during this period, Socio-economic development has progressed well, leading to significant demand for urban, industrial, mining and residential land. During the study period, the land use dynamics for both arable land and forest land were negative, indicating that the areas of these two land categories continued to decrease. Among them, arable land decreased most rapidly during the 2010–2015 period, with the greatest reduction in area.

(3) The land use dynamics index rose gradually during the study period, indicating that land use types were undergoing dynamic evolution and that land use efficiency was improving. The comprehensive land use index was above the national average, and land use types were significantly influenced by human activities.

(4) Land use diversity in Huaxi District exhibited a trend towards diversification, with the land use diversity index increasing throughout the study period. This suggests that both the complexity of land use and the variety of land use types in Huaxi District are currently in a phase of development.

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Funding

This research received no external funding.

Conflicts of Interest

The authors declare no conflict of interest.

Acknowledgment

This paper is an output of the science project.

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