

Analysis of the Spatiotemporal Evolution of the Green Space Pattern in the Central Urban Area of Zhengzhou City

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Abstract: With the continuous advancement of urbanization, exploring the evolution law of the green space pattern in the central urban area of Zhengzhou can provide a theoretical basis for improving the ecological environment and assisting the sustainable development of the city. Taking the central urban area of Zhengzhou as the research area, based on the GF remote sensing images of three periods in 2015, 2020 and 2024, this paper uses GIS and RS methods, random forest classification, and land use transfer matrix to conduct a quantitative study on the law of the spatiotemporal evolution of green space. The results show that: (1) From 2015 to 2024, the area of green space in the central urban area of Zhengzhou continued to decrease, from 522.85 km² to 442.84 km². The quantity and scale of various types of green space showed an evolution trend of "three decreases, one increase, and an overall decline". (2) The area of green space showed an increasing trend along the ring road, and a large amount of green space was concentrated outside the Fourth Ring Road. (3) From 2015 to 2020, the transfer types of the green space area in the central urban area were ranked as follows: cultivated land, forest land, grassland, and water area. From 2020 to 2024, the transferred area of forest land was slightly smaller than that of grassland.

Keywords: Green space; spatiotemporal evolution; central urban area of Zhengzhou; RS and GIS; transfer matrix.

1. Introduction

Urban Green Space refers to all areas covered by vegetation in the urban environment [1]. It includes mountains, hills, water bodies, and wastelands covered by artificial and natural vegetation, encompassing non-building spaces such as urban green areas, agricultural land, and water areas. With the rapid urbanization process and the continuous expansion of the urban built-up area, the urban green area is constantly shrinking and has become a scarce resource. Moreover, the improvement of the economic development level has prompted people to pay more attention to a green and leisure life. In recent years, the spatio-temporal changes of green space have become the key basis for optimizing the urban green space system, and the evolution of land use has become the foundation for studying the factors affecting the distribution of green space and changes in the landscape pattern [2].

2. Data Sources and Research Methods

2.1. General situation of the study area

The research area of this paper is the central urban area of Zhengzhou City, which includes five administrative districts, namely Jinshui District, Huiji District, Zhongyuan District, Erqi District, and Guancheng Hui District, with a total area of approximately 1033 square kilometers. The Zhengzhou Natural Resources and Planning Bureau, in accordance with national and local laws and regulations, urban development strategies, and actual needs, has planned the central urban area of Zhengzhou City into five ring roads.

2.2. Data Sources and Preprocessing

This paper is based on high-resolution remote-sensing original images. Data pre-processing such as radiometric calibration, atmospheric correction, geometric correction,

image mosaicking, and cropping is carried out in the ENVI 5.6 software, and a total of three-phase remote-sensing images for 2015, 2020, and 2024 are obtained. Subsequently, according to the standard of GB/T 21010-2017 "Classification of current land use", the remote-sensing images are classified into six categories: Cultivated land, Forest land, Grassland, Water body, Construction land, and Unused land. Among them, Cultivated land, Forest land, Grassland, and Water body are green spaces, while Construction land and Unused land are non-green spaces.

2.3. Research Methods

2.3.1. Random Forest Classification

The Random Forest algorithm is a classification model, it's an ensemble of several decision trees, which trains and predicts samples using multiple trees, and the final classification result is determined by the voting of multiple tree classifiers [3]. The collection of sample data includes two forms: field research and point selection from GF remote sensing images. The resolution of the high-resolution images is 2m. In this paper, visual point selection based on remote sensing images is chosen. Sample selection is carried out by dividing regions according to the topographic characteristics of each administrative region to ensure a uniform distribution and sufficient quantity of training samples and validation samples in each administrative region.

2.3.2. Land Use Transfer Matrix

The area change of green space is one of the basic indicators reflecting the current situation and change law of green space. In order to understand the types of green space and the transformation characteristics between land types more deeply and meticulously, this study uses the land use matrix to express the types of green space and the conversion between green space and non-green space. The transfer matrix can clearly reflect the mutual transformation between various land use types during the study period in terms of

quantity [4]. This is a mathematical method derived from the quantitative description of system states and state transitions in systems analysis. Its mathematical expression is as follows:

$$P = \begin{bmatrix} P_{11} & \cdots & P_{1j} \\ \vdots & \ddots & \vdots \\ P_{i1} & \cdots & P_{ij} \end{bmatrix} (i = 1,2,3,\dots; j = 1,2,3,\dots, n) \quad (1)$$

In the formula: P represents the types of green spaces in the study area, *i* represents the types of green spaces at the beginning of the analysis period, *j* represents the types of green spaces at the end of the analysis period, *P_{ij}* represents the area quantity of green spaces transferred from unit type *i* to unit type *j* within the study period. The rows represent the transfer direction of green spaces, and the columns represent the transfer sources of green spaces.

3. Results and Analysis

3.1. Overall Changes in Green Space

Table 1 The area change of green space is the basis for studying its pattern change. The changes in the area and proportion of different green spaces fully demonstrate the evolution of the green space pattern in the central urban area. From 2015 to 2024, the total area of green space in the central urban area showed a downward trend, decreasing from 522.85 km² in 2015 to 442.84 km² in 2024, with a 7.75% decrease in the proportion of the total area. In 2015, the total area of green space in the central urban area was 522.85 km², accounting for 50.62% of the total area of the central urban area. The areas of various types of green spaces were as follows: cultivated land (244.43 km², 23.66%) > forest land (178.59 km², 17.29%) > grassland (71.3 km², 6.91%) > water area (28.53 km², 2.76%). Cultivated land and forest land were the largest types of green spaces. In 2020, the total area of green

space in the central urban area was 518.05 km², accounting for 50.15% of the total area of the central urban area. The areas of various types of green spaces were as follows: cultivated land (224.37 km², 21.72%) > forest land (137.43 km², 13.3%) > grassland (115.18 km², 11.15%) > water area (41.07 km², 3.98%). Cultivated land, forest land, and grassland were the largest types of green spaces. In 2024, the total area of green space in the central urban area was 442.84 km², accounting for 42.87% of the total area of the central urban area. The areas of various types of green spaces were as follows: cultivated land (208.96 km², 20.23%) > forest land (121.12 km², 11.73%) > grassland (70.57 km², 6.83%) > water area (42.19 km², 4.08%). Cultivated land and forest land were the largest types of green spaces.

From 2015 to 2024, cultivated land and forest land were the green spaces with the largest decline. They decreased from 244.43 km² and 178.59 km² in 2015 to 208.96 km² and 121.12 km² in 2024 respectively, with a decrease of 3.43% and 5.56% in the proportion of the total area. The grassland showed a trend of first increasing and then decreasing. It increased from 71.3 km² in 2015 to 115.18 km² in 2020, and then decreased to 70.57 km² in 2024, with an overall decrease of 0.08% in proportion. The water area gradually increased from 28.53 km² in 2015 to 42.19 km² in 2024, with an increase of 1.32% in proportion. The green space in the central urban area decreased by a total of 80.01 km² from 2015 to 2024. After 2015, the increase in construction land and the decrease in cultivated land, forest land, and grassland increased simultaneously, and the increase and decrease remained highly consistent, indicating that the increase in construction land in the central urban area was in a significant positive proportion to the decrease in cultivated land, forest land, and grassland during this period, and the degree of urbanization continued to increase.

Table 1. Statistical Table of the Area of Land Use Types in the Central Urban Area of Zhengzhou City from 2015 to 2024.

Type	First-level indicators	2015 /km ²	Proportion (%)	2020 /km ²	Proportion (%)	2024 /km ²	Proportion (%)
Green Space	Cultivated land	244.43	23.66	224.37	21.72	208.96	20.23
	Forest land	178.59	17.29	137.43	13.3	121.12	11.73
	Grassland	71.3	6.91	115.18	11.15	70.57	6.83
	Water body	28.53	2.76	41.07	3.98	42.19	4.08
Non-green space	Construction land	459.30	44.46	472.54	45.75	524.73	50.80
	Unused land	50.77	4.92	42.37	4.10	65.40	6.33
Total green space		522.85	50.62	518.05	50.15	442.84	42.87

3.2. Changes in the Green Space Patterns of Different Ring Lines

As can be seen from Table 2, during the period from 2015 to 2024, the area of green space along the ring roads showed an increasing trend. The area of green space within the First Ring Road was the smallest. From 2015 to 2024, the areas of the four types of green space (cultivated land, forest land, grassland, and water area) within the First Ring Road were all less than 1 km². The area of green space outside the Fourth Ring Road was the largest. The total areas of green space in the First Ring Road, Second Ring Road, Third Ring Road, and Fourth Ring Road in the central urban area all showed a trend of first increasing and then decreasing. They increased from 0.92 km², 5.45 km², 16.26 km², and 130.01 km² in 2015 to 1.49 km², 7.58 km², 18.27 km², and 141.13 km² in 2020, and then decreased to 1.14 km², 6.04 km², 17.50 km², and

110.14 km² in 2024. The area of green space outside the Fourth Ring Road gradually decreased from 370.21 km² in 2015 to 308.02 km² in 2024.

3.3. Analysis of Green Space Transfer Matrix

In order to further understand the conversion situation among sub - categories of green spaces during the urbanization process in the central urban area of Zhengzhou, the land - use vector maps from 2015 - 2020 and 2020 - 2024 within the study area are subjected to data spatial overlay through overlay in Arcgis. By using the Statistics function, the conversion areas between various land types (mainly various green spaces) can be calculated specifically and meticulously. Finally, the land - use type transfer matrices for the two stages of 2015 - 2020 and 2020 - 2024 are expressed in tabular form (Table 3 and Table 4).

Table 2. Statistical Table of the Green Space Areas in Different Ring Lines of the Central Urban Area of Zhengzhou City from 2015 to 2024.

Year	Type	1st Ring Road	2nd Ring Road	3rd Ring Road	4th Ring Road	Outside 4th Ring Road
2015	Cultivated land	0.10	1.54	6.12	46.89	189.78
	Forest land	0.50	2.73	5.80	50.88	118.68
	Grassland	0.09	0.69	2.54	27.01	40.97
	Water body	0.23	0.49	1.80	5.23	20.78
	Total	0.92	5.45	16.26	130.01	370.21
2020	Cultivated land	0.56	3.19	7.54	62.48	150.60
	Forest land	0.67	2.77	3.80	27.32	102.86
	Grassland	0.15	0.99	3.54	42.56	67.94
	Water body	0.11	0.63	3.39	8.77	28.18
	Total	1.49	7.58	18.27	141.13	349.58
2024	Cultivated land	0.24	2.13	5.10	57.12	144.36
	Forest land	0.38	2.42	6.97	19.60	91.75
	Grassland	0.04	0.51	2.90	23.05	44.07
	Water body	0.48	0.98	2.53	10.37	27.84
	Total	1.14	6.04	17.50	110.14	308.02

3.3.1. Analysis of Green Space Conversion from 2015 to 2020

From 2015 to 2020, the green space area in the central urban area decreased by 4.80 km² in total. Among them, 366.32 km² was transferred out and 361.52 km² was transferred in (Table 3). Cultivated land was the main source of green space type conversion, with a total transfer - out area of 181.40 km². Among them, the transfer area within the green space was 87.85 km², and the areas converted into other types of green space were in the order of: grassland (45.31 km²) > forest land (33.91 km²) > water area (8.63 km²). The area of cultivated land converted into non - green space was 93.63 km². Its main transfer - in sources were forest land and construction land, with 52.37 km² and 66.86 km² transferred in respectively. Overall, the cultivated land decreased by 20.06 km², which was related to Zhengzhou's implementation of the policy of returning farmland to forests and grasslands and carrying out a series of measures to restore ecological balance, injecting green impetus into economic development.

The transfer volume of forest land in the green space type was second only to that of cultivated land, with a transfer - out area of 115.90 km². Among them, the transfer area within the green space was 80.01 km², and the areas converted into other types of green space were in the order of: cultivated land (52.37 km²) > grassland (24.51 km²) > water area (3.13 km²). The area of forest land converted into non - green space was 35.89 km². Its main transfer - in sources were cultivated land and construction land, with 33.91 km² and 22.42 km² transferred in respectively. The reduction of grassland area

was approximately half of that of forest land, with a transfer - out area of 58.52 km². Among them, the transfer area within the green space was 39.12 km², accounting for 66.85% of the transfer - out area. The areas converted into other types of green space were in the order of: cultivated land (24.31 km²) > forest land (13.35 km²) > water area (1.46 km²). The area of grassland converted into non - green space was 19.40 km². Its main transfer - in sources were cultivated land and construction land, with 40.31 km² and 32.42 km² transferred in respectively. Under the intervention of human activities, afforestation transformed grassland into forest land, while the wanton felling of trees also degraded forest land into grassland.

The outflow area of the water area was the smallest, only 10.42 km². The areas of the water area converted into cultivated land, forest land and grassland were all less than 1.4 km². Its main transfer - in sources were forest land and construction land, with 8.03 km² and 8.32 km² transferred in respectively. It can be seen that some water areas dried up, and people reclaimed the dry riverbeds that met the reclamation conditions into construction land. With the rapid development of the social economy and the advancement of urbanization, the demand for land is also increasing continuously. The areas of cultivated land, forest land, grassland and water area converted into construction land were 82.98 km², 30.24 km², 16.49 km² and 6.06 km² respectively, to meet the production and living needs of humans.

Table 3. Land Use Transfer Area Matrix in the Central Urban Area of Zhengzhou City from 2015 to 2020.

Type		Green space			Non-green space			area reduced	Total
		Cultivated land	Forest land	Grassland	Water body	Construction land	Unused land		
Green space	Cultivated land	—	33.91	45.31	8.63	86.98	6.65	181.40	-20.06
	Forest land	52.37	—	24.51	3.13	30.24	5.65	115.9	-41.16
	Grassland	24.31	13.35	—	1.46	16.49	2.91	58.52	43.88
	Water body	1.33	0.49	0.61	—	6.06	1.93	10.42	12.57
Non-green space	Construction land	66.86	22.42	32.24	8.32	—	15.74	145.58	13.24
	Unused land	16.60	4.58	4.68	2.01	13.40	—	41.27	-8.39
Area increase		161.47	74.75	102.35	22.95	149.17	32.88		

Note: The unit of the transfer matrix is km². The rows represent the land use types in 2015, and the columns represent the land use types in 2020. The numbers in the transfer matrix (except for the last row and the last column) are the areas where the land use type i in 2015 is converted into the land use type j in 2020. The last column and the last row are the row and column totals, representing the areas of each land use type in 2015 and 2020, respectively.

3.3.2. Analysis of Green Space Conversion from 2020 to 2024

During 2020 - 2024, the green space area in the central urban area decreased by a total of 75.21 km², with 328.44 km² transferred out and 253.18 km² transferred in (Table 4). Cultivated land is the main source of green space transfer, with a total transfer - out area of 146.79 km². Among them, the transfer area within the green space is 62.60 km². The areas transferred to other types of green space are in the order of: forest land (31.99 km²) > grassland (29.16 km²) > (3.05 km²), and the area transferred to non - green space is 84.19 km². Its main sources of transfer - in are forest land and grassland, with 39.05 km² and 52.64 km² transferred in respectively.

The transfer volume of grassland within the green space is second only to that of cultivated land, with a transfer - out area of 96.75 km². Among them, the transfer area within the green space is 67.54 km². The areas of grassland transferred to other types of green space are in the order of: cultivated land (52.64 km²) > forest land (13.87 km²) > water area (1.03 km²); the area of grassland transferred to non - green space is 37.21 km², accounting for about 38.46% of the outflow area. Its main sources of transfer - in are cultivated land and forest land, with 29.16 km² and 10.55 km² transferred in respectively. The transfer - out area of forest land is 71.58 km², among which the transfer area within the green space is 50.06 km², accounting for 69.93% of the outflow area; the areas of forest land transferred to other types of green space are in the order of: cultivated land (39.05 km²) > grassland (10.55 km²) > water area (0.46 km²); the area of forest land transferred to non - green space is 21.52 km². Its main sources of transfer - in are cultivated land and grassland, with 31.99 km² and 13.87 km² transferred in respectively. It can be seen that forest land and grassland are transferred to cultivated land, which is driven by the benefits brought by the adjustment of the agricultural structure.

The transfer - out area of the water area is the smallest, only 13.32 km². The areas of the water area transferred to cultivated land, forest land and grassland are 2.22 km², 0.5 km² and 1.02 km² respectively. Its main sources of transfer - in are construction land and unused land, with 8.2 km² and 2.68 km² transferred in respectively. The areas of cultivated land, forest land, grassland and water area transferred to construction land are 64.14 km², 15.50 km², 25.98 km² and 7.52 km² respectively.

3.3.3. Analysis of Area Conversion of Green Space from 2020 to 2024

From 2020 to 2024, the green space area in the central urban area decreased by a total of 75.21 km², with 328.44 km² transferred out and 253.18 km² transferred in (Table 4). Cultivated land was the main source of green space transfer, with a total transfer out of 146.79 km². Among them, the transfer area within the green space was 62.60 km², and the areas transferred to other types of green space were in the order of: forest land (31.99 km²) > grassland (29.16 km²) > (3.05 km²), and the area transferred to non - green space was 84.19 km². Its main sources of transfer in were forest land and grassland, with 39.05 km² and 52.64 km² transferred in respectively.

The transfer volume of grassland within the green space was second only to that of cultivated land, with a transfer - out area of 96.75 km². Among them, the transfer area within the green space was 67.54 km², and the areas of grassland transferred to other types of green space were in the order of: cultivated land (52.64 km²) > forest land (13.87 km²) > water area (1.03 km²); the area of grassland transferred to non - green space was 37.21 km², accounting for about 38.46% of the outflow area. Its main sources of transfer in were cultivated land and forest land, with 29.16 km² and 10.55 km² transferred in respectively. The transfer - out area of forest land was 71.58 km², among which the transfer area within the green space was 50.06 km², accounting for 69.93% of the outflow area; the areas of forest land transferred to other types of green space were in the order of: cultivated land (39.05 km²) > grassland (10.55 km²) > water area (0.46 km²); the area of forest land transferred to non - green space was 21.52 km². Its main sources of transfer in were cultivated land and grassland, with 31.99 km² and 13.87 km² transferred in respectively. It can be seen that forest land and grassland were transferred to cultivated land, which was driven by the benefits brought by the adjustment of the agricultural structure.

The transfer - out area of the water area was the smallest, only 13.32 km². The areas of the water area transferred to cultivated land, forest land and grassland were 2.22 km², 0.5 km² and 1.02 km² respectively. Its main sources of transfer in were construction land and unused land, with 8.2 km² and 2.68 km² transferred in respectively. The areas of cultivated land, forest land, grassland and water area transferred to construction land were 64.14 km², 15.50 km², 25.98 km² and

7.52 km² respectively.

Table 4. Transfer Matrix of Land Use Types in the Central Urban Area of Zhengzhou City from 2020 to 2024.

Type	Green space			Non-green space			area reduced	Total	
	Cultivated land	Forest land	Grassland	Water body	Construction land	Unused land			
Green space	Cultivated land	—	31.99	29.16	3.05	64.14	20.05	146.79	-15.41
	Forest land	39.05	—	10.55	0.46	15.5	6.02	71.58	-16.29
	Grassland	52.64	13.87	—	1.03	25.98	11.23	96.75	-44.61
	Water body	2.22	0.5	1.02	—	7.52	2.06	13.32	1.1
Non-green space	Construction land	27.02	8.89	8.58	8.2	—	19.41	72.1	52.19
	Unused land	8.8	0.64	2.83	2.68	20.79	—	35.74	23.03
Area increase			55.89	52.14	15.42	133.93	58.77		

Note: The unit of the transfer matrix is km². The rows represent the land use types in 2020, and the columns represent the land use types in 2024. The numbers in the transfer matrix (except for the last row and the last column) are the areas where the land use type *i* in 2020 is converted into the land use type *j* in 2024. The last column and the last row are the sums of the rows and columns, representing the areas of each land use type in 2020 and 2024 respectively.

4. Conclusions and Discussion

This study systematically analyzes the changes in the green space area, the evolution of the ring road pattern, and the inter - class transfer in the central urban area of Zhengzhou from 2015 to 2024, revealing its spatio - temporal evolution characteristics. In the past decade, the urban area of Zhengzhou has expanded significantly. The total area of green space in the central urban area has decreased from 522.85 km² to 442.84 km², with a proportion decrease of 7.75%. As the types of green space with the largest proportion, the loss of cultivated land and forest land area has dominated the overall reduction of green space. The grassland area first increased and then decreased, while the water area continued to grow. In terms of spatial distribution, the green space area shows a gradient change along the ring roads, which is significantly negatively correlated with the prosperity of the ring roads. The green space area from the first to the fourth ring roads first increased and then decreased, and the area outside the fourth ring road continued to shrink.

Research has found that the evolution of green spaces in the central urban area of Zhengzhou is closely related to the national ecological civilization construction strategy and local development policies [5]. The continuous decrease in the area of green spaces from 2015 to 2024 not only reflects the encroachment of ecological space by the expansion of construction land during the rapid urbanization process, but also reflects the dynamic adjustment of the land use structure under policy intervention. Guided by the national concept of "lucid waters and lush mountains are invaluable assets", Zhengzhou has actively promoted the policy of returning farmland to forests and grasslands, resulting in the transfer of 181.40 km² of cultivated land from 2015 to 2020, of which 93.63 km² was converted into non - green spaces. This has effectively promoted the optimization of the ecological land use structure, but also exacerbated the decline in the total amount of green spaces. The transfer of forest land is affected by both policy guidance and illegal logging, and the fluctuation of grassland area is closely related to the afforestation project and agricultural structure adjustment [6]. Although the development and utilization of water areas are restricted by ecological protection policies, under the

background of a sharp increase in land demand, some dried - up water areas have still been converted into construction land.

It is worth noting that since the 18th and 19th National Congresses of the Communist Party of China, the continuous promotion of ecological civilization construction policies has significantly slowed down the rate of green space loss, verifying the positive role of national policies in improving the ecological environment. However, during 2020 - 2024, the transfer of forest land and grassland to cultivated land driven by agricultural interests, as well as the encroachment of green space by the expansion of construction land, still led to a reduction of 75.21 km² in the area of green space [7]. Although Zhengzhou City introduced an urban landscaping implementation plan in 2024 to plan the construction of new green spaces to relieve ecological pressure, the squeezing effect of rapid urbanization on green space in the early stage still requires long - term restoration. In the future, Zhengzhou City needs to further strengthen the "integration of multiple plans" mechanism, incorporate the ecological protection red line into the overall urban plan, optimize the allocation of land resources, explore the ecological compensation mechanism and green development model, and achieve the systematic protection and sustainable utilization of ecological space while ensuring urban economic development.

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