

# Study on the Evolution of Urban Green Space Patterns in Zhengzhou from 2000 to 2024

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## ABSTRACT

Urban green spaces are an essential component of urban ecosystems, and their spatiotemporal evolution and landscape structural changes have a significant impact on urban ecological functions. This study focuses on the central urban area of Zhengzhou and utilizes long-term Landsat remote sensing imagery data from 2000 to 2024. A combination of methods, including urban green space interpretation, buffer zone analysis, standard deviation ellipse, and landscape pattern indices, is applied to systematically analyze the spatiotemporal evolution characteristics and landscape pattern changes of urban green spaces. The results show that: (1) The scale of urban green spaces has continuously expanded during the study period, with the total green space area increasing from 115.79 km<sup>2</sup> to 417.00 km<sup>2</sup>, and the green space coverage rate surpassing 40%. The expansion process demonstrates a distinct phase progression, shifting from early-stage peripheral aggregation to a simultaneous "infill and outward expansion" approach. (2) The coverage of green space services has evolved from contraction to balance. The 300-meter buffer zone analysis indicates a significant improvement in green space accessibility after 2020, with near-complete coverage of the central urban area by 2024. (3) The spatial center of gravity of green spaces has generally maintained a "northwest-southeast" axial alignment, with a migration trend converging from the periphery towards the center. (4) Landscape pattern analysis shows that the increase in the number and density of patches has led to a rise in micro-level fragmentation. However, the largest patch index and connectivity index have remained at relatively high levels, maintaining a stable overall network structure for the urban green space system. The findings provide valuable insights for optimizing urban green space systems in rapidly urbanizing areas.

## KEYWORDS

Landscape Pattern; Spatiotemporal Evolution; Long-Term Remote Sensing; Urban Green Space; Zhengzhou.

## 1. INTRODUCTION

Urban green spaces are a crucial component of urban ecosystems, playing a key role in regulating urban climate, maintaining biodiversity, improving living environments, and enhancing ecosystem services [1, 2]. With the rapid urbanization process, the urban land use structure has undergone profound adjustments. The contradiction between the continuous expansion of built-up areas and the limitation of ecological spaces has become increasingly prominent. The urban green space system exhibits significant dynamic changes in terms of spatial patterns, structural integrity, and the provision of ecological services [3]. Systematically characterizing the spatiotemporal evolution of urban green spaces under long-term urbanization has become an important research topic in urban geography and landscape ecology [4].

From the perspective of research scale and methodology, existing studies often rely on single-period or short time-series remote sensing imagery to provide static descriptions of urban green space patterns, which makes it difficult to reveal the evolutionary trajectory and underlying mechanisms of green space systems during different stages of urban development. Additionally, while some studies focus on changes in green space area, they lack a comprehensive characterization of green space spatial configuration, morphological features, and network structure, thus limiting a deeper understanding of the ecological stability and structural resilience of urban green spaces [5]. Therefore, analyzing the evolution of urban green space landscape patterns from a multi-scale perspective using long-term remote sensing data is of significant importance for advancing urban ecological space research [6].

Zhengzhou, as a typical rapidly expanding provincial capital in central China, has experienced a high intensity of urbanization, with rapid growth in built-up areas and significant adjustments in urban spatial forms and functional zoning over the past two decades. Although the overall area of green space has shown a growth trend, the spatial distribution balance, service coverage, and landscape structural characteristics exhibit significant differences across various stages of development. This is particularly evident in the old urban areas and high-density residential districts, where the green space system faces issues such as increased spatial fragmentation and limited service capacity. These characteristics make Zhengzhou an ideal case for studying the evolution of urban green space landscape patterns and its structural responses in the context of rapid urbanization. Based on this, this study focuses on the central urban area of Zhengzhou, relying on multi-temporal Landsat remote sensing data from 2000 to 2024. It applies methods such as urban green space identification, buffer zone analysis, standard deviation ellipse, and landscape pattern indices to systematically characterize the long-term changes in urban green space landscape patterns from both temporal evolution and spatial structure perspectives. The study aims to reveal the staged evolutionary patterns and structural stability of green space systems in the context of rapid urbanization, providing empirical support for urban ecological space optimization and green space system planning.

## **2. STUDY AREA, DATA SOURCES AND RESEARCH**

### **2.1. Study area**

The study area is the central urban area of Zhengzhou, located in the heart of the Central Plains. Zhengzhou is situated in the central part of Henan Province, at the junction of the southern bank of the lower Yellow River and the eastern foothills of Mount Song. The administrative jurisdiction of the city includes six urban districts, five county-level cities, one county, and four functional development zones, covering a total area of 7,567.22 km<sup>2</sup>. As of 2024, the urban built-up area of the city has expanded to 1,384.51 km<sup>2</sup>, with the built-up area of the central urban area covering 774.32 km<sup>2</sup>.

### **2.2. Data sources**

This study aims to accurately extract the spatial distribution of urban green spaces. Given the inherent differences in phenological characteristics between urban green spaces and croplands in Zhengzhou, the use of single-phase NDVI indices is prone to spectral confusion, resulting in "mixed pixel" issues. To address this, we developed a method coupling spectral features with phenological trajectories. By leveraging the growth cycle patterns of major crops in Zhengzhou, multi-temporal remote sensing imagery was dynamically analyzed to remove the influence of croplands, resolving the challenges of green space identification in urban-rural transitional zones [7]. The remote sensing data used in this study were sourced from the US Geological Survey (USGS) EarthExplorer platform (<https://earthexplorer.usgs.gov/>), specifically from Landsat series satellite imagery. These included Landsat 7 ETM+ (2000, 2005, 2010) and Landsat 8-9 OLI/TIRS (2015, 2020, 2024) imagery. To

capture the characteristics of the vegetation growing season, three remote sensing images from April to September each year, during the crop active period, were used to extract urban green spaces. The cloud cover was kept below 5% to ensure the representativeness and timeliness of the vegetation data. The extraction results were evaluated for accuracy using a confusion matrix. The results showed an overall classification accuracy of  $\geq 89.3\%$  and a Kappa coefficient of  $\geq 0.85$ , indicating that the green space extraction results are highly reliable and meet the accuracy requirements for subsequent spatial analysis.

## **2.3. Researches**

### **2.3.1. Buffer Zone Analysis**

To quantitatively assess the spatial accessibility and social equity of urban green space services, this study introduces the "300-meter green space" criterion as an evaluation standard, constructing a green space service radius buffer zone model using the ArcGIS Pro platform. Based on the extracted urban green space patches, 300-meter Euclidean distance buffer zones were generated for each period's green space data. Through spatial overlay analysis, the coverage of the buffer zones on the built-up land in the central urban area was calculated. This method enables the characterization of the dynamic changes in the service area of urban green spaces from a resident's walking accessibility perspective, reflecting the expansion or contraction of green space service capacity at different stages of urban development. It provides a quantitative basis for analyzing the equity of green space spatial configuration.

### **2.3.2. Standard Deviation Ellipse**

The standard deviation ellipse is a commonly used spatial statistical analysis method that can comprehensively describe the distribution center, directionality, and dispersion of spatial elements [8]. In this study, the standard deviation ellipse method was applied to analyze the spatial distribution characteristics of urban green spaces during different periods. By calculating the spatial center of gravity of the green space patches, the overall migration trend of green space distribution was identified. At the same time, by considering the long axis, short axis, and rotation angle of the ellipse, the dominant direction of green space distribution and its temporal variation characteristics were revealed. This method helps to identify, on a macro scale, the coupling relationship between the evolution of urban green space spatial structure and the direction of urban expansion.

### **2.3.3. Landscape Pattern Analysis**

Based on landscape ecology theory, this study selects eight typical landscape indices that reflect the fragmentation, shape complexity, connectivity, and structural stability of green spaces. Using Fragstats 4.3 software, a quantitative analysis of the landscape patterns of urban green spaces in the study area was conducted. By calculating and comparing multi-temporal green space data from 2000 to 2024, the study systematically characterizes the changes in urban green space landscape patterns during the long-term urbanization process, with a focus on analyzing patch structure adjustments, changes in spatial connectivity, and overall network stability. This analysis helps to reveal the response characteristics of how the evolution of urban green space spatial configuration impacts the potential ecological service functions.

To further explore the fluctuations in the evolution of landscape pattern characteristics of green spaces in the central urban area of Zhengzhou during the urbanization process, the study introduces the coefficient of variation (CV) for evaluation. The coefficient of variation (CV), as a statistical measure of data dispersion, effectively eliminates the influence of dimensionality and visually reflects the volatility of each landscape pattern index over time. A higher CV value indicates stronger interference from urban development, leading to greater instability in the temporal evolution of the index. Conversely, a lower CV value suggests that the index has greater structural inertia and stability.

### 3. RESULTS ANALYSIS

#### 3.1. Spatiotemporal Evolution of Green Spaces

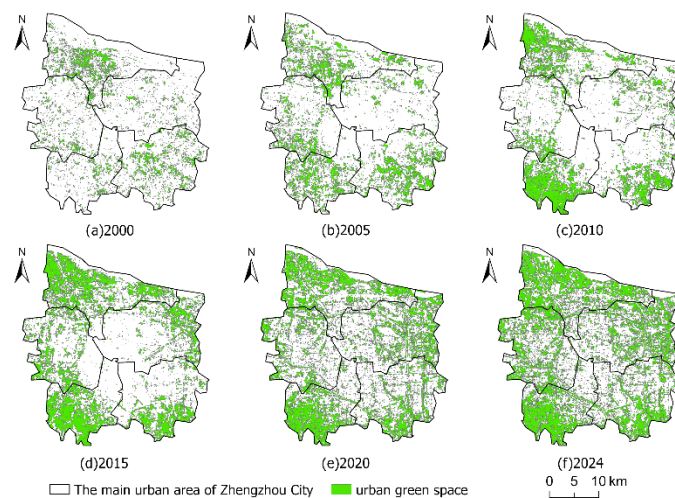
Based on the interpretation of long-term Landsat remote sensing imagery data from 2000 to 2024, this study quantitatively evaluated the scale, spatiotemporal distribution, and service efficiency of urban green spaces in the central urban area of Zhengzhou. The analysis results show that over the past two decades, the evolution of Zhengzhou's green space system has not followed a simple linear growth pattern but rather exhibits significant phased evolution characteristics.

In terms of the overall green space scale (Table 1), the green space area in the central urban area of Zhengzhou has experienced continuous and substantial growth. Statistical data reveals that the total green space area increased from 115.79 km<sup>2</sup> in 2000 to 417.00 km<sup>2</sup> in 2024, with a cumulative net increase of 301.22 km<sup>2</sup>, corresponding to an average annual growth rate of 12.55 km<sup>2</sup> and a cumulative growth of 260.13%. Meanwhile, the green space coverage rate rose from 11.20% in 2000 to 40.35% in 2024. This significant change reflects the fact that, during the rapid urbanization process, Zhengzhou has not only effectively curbed the chaotic encroachment of built-up land on ecological space but has also achieved a synchronized optimization of ecological space supply and urban expansion.

**Table 1.** Urban Green Space Area in the Central Urban Area of Zhengzhou

Year	Green Space Area (km <sup>2</sup> )	Area Proportion (%)	Time Period	Area Change (km <sup>2</sup> )
2000	115.79	11.20%	2000—2005	77.64
2005	193.43	18.72%	2005—2010	36.09
2010	229.52	22.21%	2010—2015	76.89
2015	306.41	29.65%	2015—2020	42.27
2020	348.68	33.74%	2020—2024	68.32
2024	417.00	40.35%	2000—2024	301.21

A more detailed analysis of the temporal evolution characteristics reveals that the growth of green space has not been a simple linear accumulation but rather shows clear phased fluctuations. The periods of 2000-2005, 2010-2015, and 2020-2024 represent three high-speed expansion windows for green space. Notably, during 2020-2024, the green space coverage rate exceeded 40% as the development of urban green space accelerated.



**Figure 1.** Distribution of Urban Green Spaces in the Central Urban Area of Zhengzhou from 2000 to 2024

From the perspective of spatial morphological evolution (Figure 1), the landscape pattern of urban green spaces in the central urban area of Zhengzhou has undergone a transformation from discrete

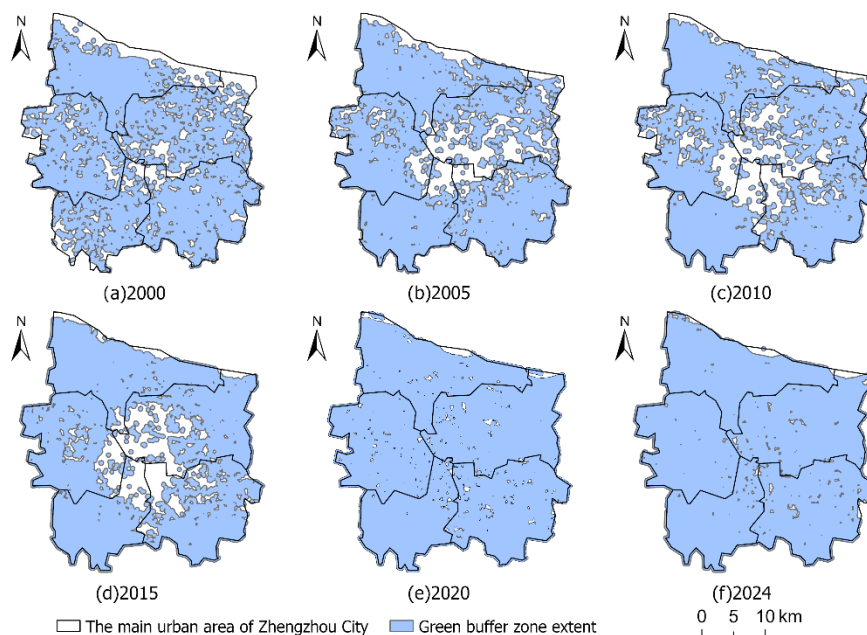
fragmentation to network aggregation over the past 24 years, exhibiting significant spatial heterogeneity. In 2000, urban green space development was still in its early stages, and a systematic network of green spaces had not yet been formed. Green space patches were scattered, particularly in the northwest and southeast regions of the central urban area, while the densely populated central built-up areas had limited green space patches.

From 2000 to 2015, green space in the central urban area grew rapidly, particularly around the urban periphery. Green space patches in the southern and northern parts of the city became significantly denser. The preliminary formation of the southern ecological conservation area and the northern Yellow River ecological belt became evident. Despite the surge in green space in the peripheral areas, connectivity within the core urban area remained insufficient, and ecological corridors were fragmented. This led to a "more green space on the periphery, less in the center" hollow distribution pattern.

Between 2020 and 2024, the urban green space system entered a comprehensive and deepening phase of integrated development. With the simultaneous implementation of the "demolition for green space" and "green space infill" strategies in the old city and systematic planning in the new districts, the green space density within the central urban area significantly increased. By 2024, a green network covering the entire area had been largely established. The connectivity and aggregation of green space patches were substantially enhanced, laying a solid physical foundation for the construction of a "National Ecological Garden City." However, spatial analysis reveals that there are still localized green space service gaps in the core areas of the old city, and some green spaces have a relatively simple functional structure. There is still potential for further improvement in the ecological service efficiency of these green spaces.

### 3.2. Buffer Zone Results Analysis

To further assess the social equity and spatial accessibility of green space services, this study introduces the "300-meter green space" criterion as an evaluation indicator. The 300-meter service radius buffer zone model was constructed using ArcGIS Pro software to quantitatively measure the spatial coverage of green space services (Figure 2).



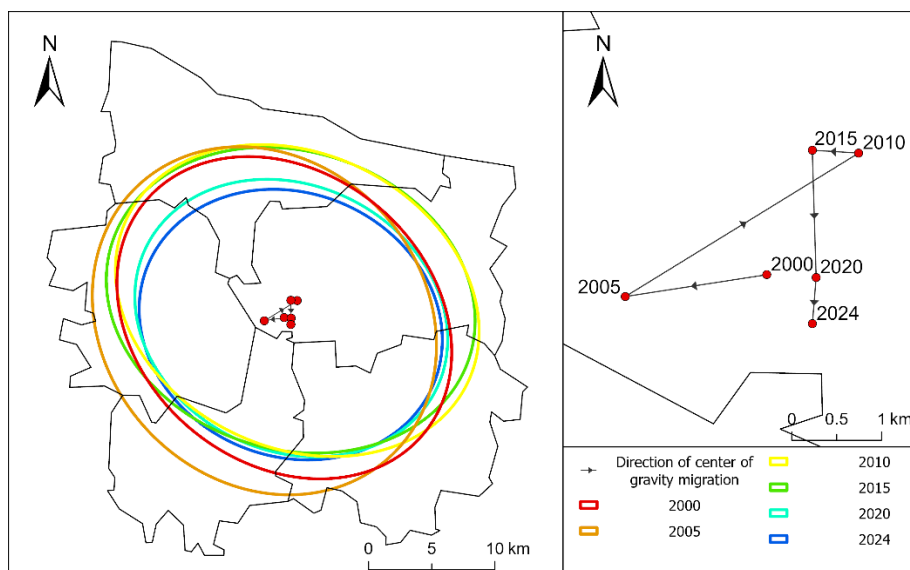
**Figure 2.** Buffer Zone Analysis of Urban Green Spaces from 2000 to 2024

The spatiotemporal evolution of the buffer zone analysis reveals a "U-shaped" pattern of evolution that offers valuable insights: the coverage of urban green spaces underwent a nonlinear process of

"contraction—fluctuation—expansion." The study found that the green space buffer zone coverage in 2000 was even better in some areas compared to the periods between 2005 and 2015. This retrogression in coverage suggests that during the early stages of urbanization, the expansion of urban land use outpaced the planning of ecological spaces, leading to the erosion of scattered green spaces in the core areas by high-intensity construction activities. As a result, residents faced a challenging "difficulty in accessing green spaces" situation. However, this trend changed after 2020. With the deepening of urban ecological restoration efforts, the layout of urban green spaces gradually shifted from "emphasizing scale" to "emphasizing service." The results from 2024 show that the 300-meter buffer zone has largely achieved full coverage of residential land in the central urban area. The integration of residential living spaces with ecological spaces has been significantly enhanced, and green space accessibility has improved remarkably. This indicates that Zhengzhou has essentially achieved its planning goal of "300-meter green space accessibility."

### 3.3. Standard Deviation Ellipse Results Analysis

To reveal the discrete characteristics and spatiotemporal evolution trajectory of green space distribution in the central urban area of Zhengzhou, this study introduces the standard deviation ellipse and center of gravity migration model for quantitative characterization. Figure 3 illustrates the spatial patterns of the standard deviation ellipse and center of gravity migration of urban green spaces from 2000 to 2024. Overall, the evolution of green space in Zhengzhou presents a spatiotemporal characteristic of a shift from a dispersed to a more concentrated distribution, with the green space center of gravity migrating southeast.



**Figure 3.** Changes in the Migration of the Urban Green Space Center of Gravity from 2000 to 2024

In terms of the standard deviation ellipse spatial morphological evolution, the distribution of green spaces in the central urban area of Zhengzhou has consistently maintained a significant northwest-southeast axial characteristic. By analyzing the area and changes in the long and short axes of the standard deviation ellipse, it was found that the spatial distribution of green spaces exhibited a phased characteristic of "first expanding outward from the city center, then converging towards the city center." This reflects the relative differences in green space growth between the urban core and peripheral areas. Specifically, from 2000 to 2015, the area of the standard deviation ellipse remained high, especially between 2010 and 2015, when the center of green space distribution consistently stayed in the northeast direction, indicating that new green spaces were primarily developed in the northeastern part of the city. After 2020, the range of the standard deviation ellipse showed a significant contraction, reaching its minimum by 2024. This spatial convergence phenomenon suggests that, as the city entered a mature development stage, the focus of green space development

returned to the central urban area. Through measures such as "demolition for green space," "green infill," and the renovation of old neighborhoods, the density of green spaces in the central urban area significantly increased, enhancing the aggregation of green space distribution around the center.

The spatiotemporal dynamics of the center of gravity migration trajectory show a complex "spiral" evolutionary pattern. The center of gravity remained within Jinshui District and did not move away from the geometric center of the central urban area. The migration trajectory reflects the shifting focus of green space development at different stages. From 2000 to 2005, the center of gravity shifted southwest, mainly due to the acceleration of greening in the western high-tech zone and the green restoration of old industrial areas, which increased the spatial weight of green spaces in the western part of the city. From 2005 to 2010, the center of gravity jumped northeast, with a large movement in a clear direction. This was due to large-scale urban green space development in the Zhengdong New District, which quickly shifted the green space center of gravity towards the eastern new city. Between 2010 and 2024, the trajectory of the center of gravity showed a trend of first moving westward and then southward. This reflects how ecological restoration in the western and central parts of the old city balanced the excessive development in the eastern part. From 2015 to 2024, the center of gravity continued to shift southward, which was closely linked to the completion of green space projects in Erqi District, Guancheng Hui District, and the ecological corridor of the South-to-North Water Diversion Project. This has made the southern part of the city a new hotspot for green space expansion in recent years, gradually establishing a balanced ecological spatial structure between the north and south of the city.

### 3.4. Green Space Landscape Pattern Features Analysis

This study, based on landscape ecology theory, selects eight key landscape indices that can characterize fragmentation, shape complexity, connectivity, and stability. These indices are quantitatively calculated using the Fragstats 4.3 platform. Through dynamic monitoring of the green space landscape patterns in the study area from 2000 to 2024, the study reveals the evolutionary patterns of the spatial configuration of green spaces in the central urban area of Zhengzhou during the urbanization process and the potential responses of its ecological service functions.

**Table 2.** Urban Green Space Landscape Pattern Indices

Year	NP	PD	LPI	ED	LSI	FRAC MN	COHESION	AI
2000	5825	5.64	1.21	40.46	97.34	1.07	97.16	86.55
2005	4492	4.35	0.90	47.98	89.66	1.08	98.17	90.42
2010	3719	3.60	4.89	43.14	74.64	1.07	99.12	92.70
2015	3461	3.35	6.45	52.04	78.08	1.07	99.47	93.39
2020	6712	6.50	5.09	75.61	105.92	1.08	99.13	91.56
2024	5887	5.70	5.20	79.32	101.59	1.08	99.27	92.61

#### 3.4.1. Landscape Fragmentation Evolution Characteristics

Patch number (NP), patch density (PD), and the largest patch index (LPI) were selected to characterize the degree of fragmentation and dominance in the green space landscape. The calculation results show (Table 2) that the green space landscape of Zhengzhou has undergone a nonlinear evolution process of "integration—fragmentation—re-optimization." Specifically, from 2000 to 2015, NP and PD showed a significant downward trend, indicating that during this period, many scattered small green space patches were integrated due to urban renovation and construction. However, from 2015 to 2020, NP and PD surged, which is closely related to Zhengzhou's recent policies such as "300-meter green space, 500-meter park" and the construction of "pocket parks." The increase in numerous small green spaces not only improved services but also objectively increased landscape fragmentation. Notably, the LPI significantly increased after 2010 and remained high, indicating that while small patches increased, large core green spaces were retained and expanded. This formed a

composite pattern of large patches as the main feature, supplemented by small patches, effectively mitigating the ecological fragmentation effects caused by pure fragmentation.

### 3.4.2. Landscape Shape Complexity and Heterogeneity Characteristics

Edge density (ED), landscape shape index (LSI), and mean patch fractal dimension (FRAC\_MN) were selected to study the geometric morphology of green space patches and the degree of disturbance. Edge density (ED) showed a continuous upward trend during the study period, reaching its peak of 79.32 in 2024, indicating that the interface between green spaces and built-up land continued to extend, significantly enhancing the edge effect. This reflects that urban green spaces were spatially fragmented by road networks and building layouts, with boundaries becoming more complex. The landscape shape index (LSI) displayed a "U-shaped" trend of decreasing and then increasing, corresponding with changes in the fractal dimension (FRAC\_MN). The low point of LSI in 2010 suggested that the green spaces were more regular during this period. However, the subsequent increase in LSI after 2010 reflected the process of urban ecological restoration, during which green spaces gradually returned to irregular shapes, enhancing the spatial heterogeneity of the landscape.

### 3.4.3. Landscape Connectivity and Spatial Aggregation Characteristics

The patch cohesion index (COHESION) and aggregation index (AI) were used to quantify the spatial adjacency relationship between green space patches and the connectivity potential of the green space network. The data show that from 2000 to 2024, although fragmentation indicators fluctuated, the COHESION index, which reflects physical connectivity, maintained steady growth, and the AI index remained high, above 90. This result indicates that while the total amount of green space in Zhengzhou expanded, the city focused on the construction of ecological corridors and group-type green spaces, reducing the physical distance between patches. High aggregation implies that green spaces tend to cluster in space. Through systematic ecological planning, Zhengzhou achieved the organic integration of green spaces, which is conducive to maintaining biodiversity and enhancing the large-scale ecological cooling island effect.

### 3.4.4. Temporal Stability of Landscape Pattern Indices

Based on the coefficient of variation (CV) calculated for landscape pattern indices from 2000 to 2024, the green space landscape in Zhengzhou exhibited distinct characteristics: "high-frequency fluctuations in size and shape, with relative stability in network structure."

**Table 3.** Coefficient of Variation for Urban Green Space Landscape Pattern Indices

	NP	PD	LPI	ED	LSI	FRAC MN	COHESION	AI
CV	23.96%	23.96%	53.47%	27.21%	12.75%	0.18%	0.82%	2.51%

The calculation results of the high volatility in the scale and edge characteristics indicate that the coefficient of variation (CV) for the largest patch index (LPI) reached 53.47%, the highest among all the indices. This reveals that during the study period, core green space patches (such as large integrated parks and waterfront green belts) underwent dramatic reorganization and spatial replacement. Additionally, edge density (ED) (CV = 27.21%), patch number (NP), and patch density (PD) (both with CVs of 23.96%) also exhibited high variability. This suggests that the "quantity" and "edge morphology" of green spaces are the most sensitive factors responding to urbanization disturbances. As the alternation of old city renovation and new city expansion progressed, green space patches continuously underwent a dynamic process of "being encroached—being fragmented—being re-planned—being reconstructed," leading to significant fluctuations in fragmentation and edge complexity over the years.

In contrast, the stability of spatial configuration and network structure (low CV value group) sharply contrasts with the extreme fluctuations in the scale indicators, demonstrating that the green space spatial configuration indicators exhibit strong stability. The coefficient of variation for the mean patch fractal dimension (FRAC\_MN) was only 0.18%, and the CV for the patch cohesion index

(COHESION) and aggregation index (AI) were also very low, at 0.82% and 2.51%, respectively. This indicates that, despite the continuous changes in the specific location, number, and size of green spaces in Zhengzhou, the overall spatial organizational pattern and ecological network framework have maintained a high level of resilience. The green space system has not undergone structural changes due to urban construction; on the contrary, through ongoing planning control and ecological restoration, the physical adjacency and functional connectivity between green space patches have remained at a relatively stable level, ensuring the continuity of urban basic ecological functions.

In summary, the evolution of the green space landscape pattern in the central urban area of Zhengzhou from 2000 to 2024 exhibits a dual characteristic of micro-level dynamism and macro-level stability. The differentiated distribution of the coefficients of variation objectively reflects the adaptive mechanism of urban green spaces in responding to rapid urbanization, where local patches undergo dramatic turnover to adapt to urban morphological changes while maintaining the relative stability of the overall ecological network structure.

## 4. CONCLUSION

This study systematically analyzes the evolution patterns and spatial structure characteristics of urban green spaces in the central urban area of Zhengzhou from 2000 to 2024, based on long-time series Landsat remote sensing imagery data, focusing on both spatiotemporal evolution characteristics and landscape pattern indices. The main conclusions are as follows:

(1) During the study period, the scale of urban green spaces in the central urban area of Zhengzhou continued to expand, with the total green space area increasing from 115.79 km<sup>2</sup> in 2000 to 417.00 km<sup>2</sup> in 2024, and the green space rate exceeding 40%. The expansion of green space exhibited significant stage characteristics, initially concentrated on the periphery with insufficient green coverage in the center, and gradually shifting towards a development model of "infill and outward expansion."

(2) The coverage of urban green space services evolved from contraction to equilibrium. The 300-meter buffer zone analysis indicated that during the rapid urbanization phase, the coverage of green space services temporarily declined, but from 2020 onwards, it improved significantly, achieving near full coverage of the central urban area by 2024. The focus of green space configuration shifted from scale-oriented development to service equity-oriented planning.

(3) The center of gravity of green spaces exhibited a migration trend from the periphery to the center, maintaining an overall northwest-southeast axial characteristic. The migration path of the center of gravity showed a high degree of consistency with the spatial expansion of Zhengzhou and the development of key functional areas, reflecting the response of urban green space layout to adjustments in the city's development strategy.

(4) Landscape pattern analysis revealed that the increase in patch number and density led to higher fragmentation at the micro level, but the largest patch index and connectivity index remained high. The coefficient of variation for relevant structural indicators was low, showing that the overall network structure of the urban green space system remained stable, with a certain degree of ecological continuity and structural resilience.

These findings provide a detailed understanding of the evolution of urban green space in Zhengzhou, highlighting the adaptive responses of green spaces to rapid urbanization and the importance of maintaining ecological connectivity and resilience through strategic planning and development.

## REFERENCES

- [1] Yan, S., Li, X., Li, T., et al. (2024). Measures and pathways for the construction of urban park green spaces under the context of open sharing. *Landscape Architecture*, 31(02), 12-8.

- [2] Han, L., Zhang, R., Wang, J., et al. (2024). Spatial synergistic effect of urban green space ecosystem on air pollution and heat island effect. *Urban Climate*, 55, 101940.
- [3] Wu, S., Wang, D., Yan, Z., et al. (2023). Spatiotemporal dynamics of urban green space in Changchun: Changes, transformations, landscape patterns, and drivers. *Ecological Indicators*, 147, 109958.
- [4] Xu, H., Xie, J., Li, X., et al. (2024). Spatiotemporal changes of urban green space landscape pattern and emergency shelter function in Beijing from 2005 to 2020. *Ecology Journal*, 43(08), 2247-2256.
- [5] Li, Z., Gan, X., Pan, F., et al. (2024). Spatial matching of supply and demand for park green space cultural ecosystem services: A case study of the central urban area of Chengdu. *Chinese Garden*, 40(08), 104-110.
- [6] Chu, M., Lu, J., & Sun, D. (2022). Influence of urban agglomeration expansion on fragmentation of green space: A case study of Beijing-Tianjin-Hebei urban agglomeration. *Land*, 11(2), 275.
- [7] Men, G., He, G., & Wang, G. (2021). Concatenated residual attention UNet for semantic segmentation of urban green space. *Forests*, 12(11), 1441.
- [8] Liu, W., Li, H., Xu, H., et al. (2023). Spatiotemporal distribution and driving factors of regional green spaces during rapid urbanization in Nanjing metropolitan area, China. *Ecological Indicators*, 148, 110058.