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Spatiotemporal Analysis of Urban Green Infrastructure Landscape Pattern Dynamics Based on MSPA: A Case Study of the Jialu River Basin in Zhengzhou City

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Abstract. With the rapid urbanization of Zhengzhou City, the continuous expansion of construction land and population has led to extensive occupation of arable land and forested areas, resulting in a decline in biodiversity, fragmentation of green infrastructure (GI), and weakened connectivity, thereby threatening ecological security. This study focuses on the Yellow River Basin within Zhengzhou, employing landscape ecology principles, and utilizing Morphological Spatial Pattern Analysis (MSPA) alongside landscape pattern indices to quantitatively assess the spatial configuration of GI across three temporal points: 2015, 2020, and 2025. The results indicate a consistent reduction in total GI area, significant contraction of core zones, increased landscape fragmentation, and decreased patch connectivity. Although the areas of edge zones and ring roads have expanded, the proportion of isolated patches has risen, and overall connectivity remains insufficient. The primary driving factors include rapid urban expansion, land resource pressures from demographic and economic growth, ecological degradation coupled with climate change, industrial restructuring, and the reconfiguration of green spaces. The findings suggest that Zhengzhou must optimize the spatial arrangement of GI, enhance the protection of ecological source areas and corridor connectivity, and implement systematic management strategies to effectively mitigate ecological degradation and support sustainable urban development.

Keywords: Green Infrastructure, MSPA, Landscape Pattern, Ecological Corridors.

1. Introduction

With the rapid urban development, the expansion of urban construction land and population size has increasingly encroached upon the habitats of biological species. This has led to the emergence of various urban environmental issues, including landscape fragmentation, the urban heat island effect, air pollution, and a decline in biodiversity [1]. Green infrastructure (GI) is a network of green spaces that supports natural life systems by connecting ecologically functional natural and semi-natural open spaces within and around urban areas. Composed of ecological sources, corridors, and nodes, GI can improve ecological conditions, enhance landscape functions, and promote sustainable urban development [2,3]. Since changes in landscape types and structures within GI directly influence ecosystem service functions, it is essential to study their spatiotemporal dynamics. Moreover, establishing an ecologically healthy green infrastructure network has become a critical measure for alleviating urban ecological challenges, ensuring the safety of human settlements, and supporting sustainable urban growth [4]. Recent research on urban green infrastructure networks has yielded substantial progress in theoretical understanding, technological approaches, and practical case studies [5-7]. Given the complexity and integrative nature of GI, which emphasizes the integrity, systematicity, and inherent laws of natural ecosystems and exhibits significant regional specificity, constructing urban green infrastructure based on ecosystem integrity and regional characteristics has become a focal point of current research.

Morphological spatial pattern analysis (MSPA), grounded in morphological principles, measures, segments, and identifies spatial patterns in raster images. By differentiating land use types from other natural ecological elements, MSPA accurately recognizes and extracts landscape types and structures at large spatial scales [8]. MSPA enables the identification of ecological source areas based on landscape structural attributes, considering connectivity to avoid subjective biases in source area selection, and provides clear ecological interpretations of landscape elements, making it highly operational [9,10].

This study addresses the pressing issues of ecological space compression, landscape fragmentation, and biodiversity decline prevalent during China's rapid urbanization. It holds significant theoretical and practical importance for scientifically diagnosing regional ecological health, optimizing land use patterns, and promoting sustainable urban development. The research focuses on the evolution of landscape structural types and spatial connectivity within green infrastructure, using Zhengzhou City's Jialu River Basin as a case study. A combined methodology of MSPA and landscape pattern indices was employed to process and analyze multi-temporal remote sensing data. The advantage of this approach lies in MSPA's ability to precisely identify and segment landscape structures with specific ecological functions—such as core areas and corridors—based on morphological principles, thereby effectively avoiding subjectivity in ecological source identification. Simultaneously, landscape pattern indices quantitatively characterize overall landscape fragmentation, connectivity, and heterogeneity changes. The complementary use of these methods facilitates a comprehensive analysis of structural deficiencies and driving forces within the GI network, thereby supporting in-depth research. The ultimate goal of this study is to elucidate the spatiotemporal evolution and driving mechanisms of GI landscape patterns in the Jialu River Basin from 2015 to 2025, providing scientific evidence and strategic recommendations for ecological protection, green infrastructure optimization, and land use planning in Zhengzhou. To achieve this, a series of tasks were conducted, including land use data interpretation, landscape type classification via MSPA, landscape index calculation, and comprehensive analysis of driving forces.

2. Research methodology

Remote sensing imagery for the study area in 2015, 2020, and 2025 was sourced from the Geospatial Data Cloud. Preprocessing steps included radiometric calibration, atmospheric correction, and band extraction within remote sensing image processing software, resulting in land use data with a 30-meter spatial resolution. High-resolution imagery from Google Earth served as a reference, and visual interpretation was conducted through an interactive human-computer approach. Land use classification adhered to the national standard "Land Use Status Classification" (GB/T 2010–2017), categorizing the study area into six primary classes: cropland, forest land, grassland, water bodies, construction land, and unused land. The maximum likelihood method was employed for supervised classification.

Initially, reclassification within ArcMap designated cropland, forest land, grassland, and water bodies as foreground with a value of 2, while other land use types were assigned as background with a value of 1. Following a series of processing steps, a land use type map with raster cells of 30 m × 30 m was generated (see Figure 1). Subsequently, MSPA (Morphological Spatial Pattern Analysis) was performed using Guidos software to analyze landscape patterns, with the ecological implications of MSPA landscape types summarized in Table 1.

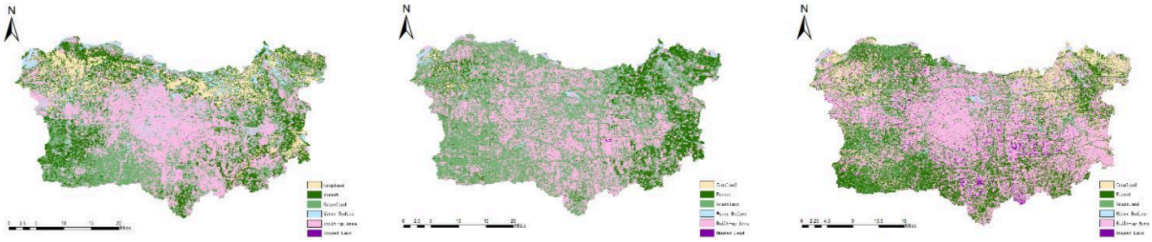

Figure 1. Land use type maps of the study area in 2015, 2020, and 2025

Table 1. Landscape types of MSPA and their ecological implications

Landscape typology	Ecological significance
Core	Larger patches can serve as ecological source areas, providing migration corridors or habitats for biological species.
Islet	Fragmented patches with low connectivity or isolated clusters within the network.
Perforation	The buffer zone between the core area and internal non-green landscape patches, namely the edge of the internal patches, exhibits edge effects.
Edge	The buffer zone between the core area and the non-green landscape patches in the periphery, specifically at the edge of the peripheral patches, exhibits edge effects.
Loop	The elongated corridors within the same core zone serve as pathways for biological migration and energy exchange within the core region.
Bridge	The elongated corridors connecting core regions are of critical importance for species dispersal and energy exchange.
Branch	A region connected to only one boundary with the edge zone, bridging zone, ring road, or pore.

Finally, based on the land use maps for 2015, 2020, and 2025, four natural ecological elements—cropland, forest land, grassland, and water bodies—were extracted as foreground, while non-natural elements such as construction land served as background. MSPA landscape type maps were produced for the study area, enabling an analysis of the spatiotemporal dynamics of the GI (Geospatial Infrastructure) landscape pattern within the region. For a best viewing experience the used font must be Times New Roman, on a Macintosh use the font named times, except on special occasions, such as program code.

3. Results

Figure 2 illustrates the landscape type maps of the study area for the years 2015, 2020, and 2025. It is evident that, due to the continuous expansion of construction land, the green infrastructure (GI) patches in the study area have progressively become fragmented from 2015 to 2025. The core zones of GI are predominantly distributed along the eastern and western edges of the region, exhibiting marked polarization. As shown in Table 2, the total GI area within the study region demonstrates a decreasing trend over this period. The maximum GI area was recorded in 2015, primarily attributable to the ongoing development and conversion of unused land into other land uses during urban expansion. Conversely, the minimum GI area was observed in 2025, indicating that the ongoing urban sprawl has encroached upon substantial green spaces within the region. From 1997 to 2019, the area of GI core zones also declined. In 2020, the core zone area was 1,069.61 km², representing a reduction of 198.38 km² compared to 2015, mainly due to the continuous development and conversion of green spaces into construction land during urban growth. By 2025, the core zone area further decreased to 743.22 km², a decline of 326.39 km² from 2015, likely driven by climate change and unsustainable land resource utilization leading to ecological degradation.

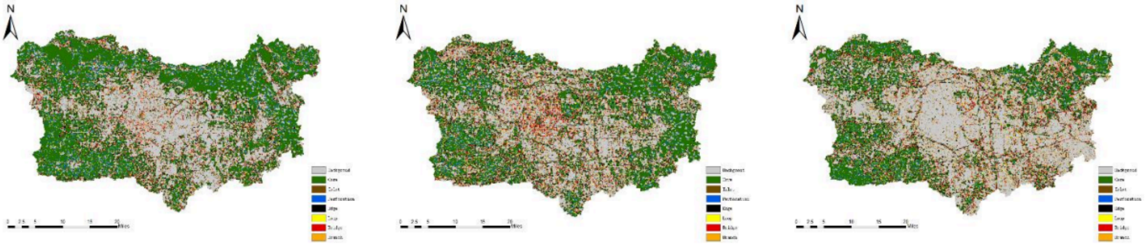

Figure 2. Landscape type maps of the study area in 2015, 2020, and 2025

Table 2. Area changes of MSPA landscape types in the study area from 2015 to 2025

Region	Year	Area/km²	Proportion%	Region	Year	Area/km²	Proportion%
	2015	1267.99	65.82		2015	48.14	2.51
Core	2020	1069.61	56.76	Loop	2020	67.67	3.59
	2025	743.22	49.87		2025	50.11	3.36
	2015	43.35	2.25		2015	119.58	6.21
Islet	2020	40.56	2.15	Bridge	2020	164.39	8.72
	2025	80.11	5.38		2025	148.41	9.96
	2015	135.91	7.06		2015	77.87	4.04
Perforation	2020	104.01	5.52	Branch	2020	106.32	5.64
	2025	55.51	3.72		2025	106.97	7.18
	2015	233.54	12.12		2015	1926.38	100
Edge	2020	331.84	17.61	Total	2020	1884.41	100
	2025	305.95	20.53		2025	1490.28	100

During the study period, the bridging zones initially expanded and then contracted, with an overall increasing trend. The peripheral zones and pores, which serve as buffer regions surrounding and within GI patches respectively, also changed accordingly. The proportion of the total GI area occupied by peripheral zones increased from 12.12% in 2015 to 20.53% in 2025, while the pore areas decreased from 7.06% to 3.27% over the same period. The expansion of peripheral zones suggests an increasing transitional buffer between core green spaces and surrounding non-green areas, potentially mitigating human disturbance to some extent. The reduction in pore areas indicates an improvement in internal ecological spaces within GI patches, as these non-ecological lands diminish. The proportion of isolated patches (islands) within the GI landscape increased by 3.13%

from 2015 to 2025, reflecting heightened fragmentation. The area of ring roads and subsidiary corridors within the study region generally increased, indicating poor connectivity among GI patches.

Table 3 presents the landscape pattern indices for the study area from 2015 to 2025. The number of patches (NP) is a common metric representing the total count of patches within a landscape type. The total patch count increased from 7,743 in 2015 to 11,791 in 2020, and further to 12,009 in 2025, indicating a continuous intensification of landscape fragmentation over the study period. The Largest Patch Index (LPI), which reflects the proportion of the largest patch relative to the total landscape, initially increased then decreased, with an overall declining trend, suggesting that large patches are becoming smaller and more dispersed, thus increasing fragmentation. The Landscape Shape Index (LSI), which measures the complexity of patch shapes, showed an increasing trend, indicating that GI patches are becoming more irregular and elongated, further signifying increased landscape fragmentation. The Contagion index (CONTAG), representing the degree of aggregation among patches, steadily decreased, implying a weakening of landscape cohesion and clustering. The Shannon Diversity Index (SHDI), indicating landscape heterogeneity, and the Shannon Evenness Index (SHEI), reflecting the uniformity of patch distribution, both increased from 2015 to 2025. This suggests that the landscape types within the study area have become more diverse and evenly distributed, likely due to the expansion of construction land and grasslands, coupled with reductions in cultivated and unused lands, leading to a more balanced and heterogeneous GI structure.

Table 3. Changes of landscape pattern indices in the study area from 2015 to 2025

Year	NP	LPI%	LSI	CONTAG%	SHDI	SHEI
2015	7743	47.341	55.726	60.032	1.084	0.552
2020	11791	48.126	61.663	57.688	1.154	0.579
2025	12009	35.745	63.607	56.832	1.204	0.612

4. Drive force analysis

Between 2015 and 2025, Zhengzhou experienced rapid urban expansion driven by the development of the national central city and the strategic initiatives of "Eastern Strengthening, Western Beautification, Southern Mobilization, Northern Stability, and Central Optimization." Large-scale development in key areas such as the Airport Economic Zone, High-tech Zone, and Zhengdong New District has led to a continuous increase in construction land, directly encroaching upon agricultural fields, forests, and unused land, thereby disrupting the existing green infrastructure network. This has resulted in a reduction of core urban areas, fragmentation of landscape patches, and decreased connectivity. Concurrently, the population grew from approximately 9.5 million to an estimated 12 million, with sustained economic growth fueling a surge in demand for infrastructure, housing, and industrial land, intensifying pressure on land resources. Particularly at the urban periphery, ecological land has been extensively converted into construction land, while the lack of coordinated management of ecological red lines, basic farmland protection zones, and urban green space systems has further threatened the integrity of the green infrastructure system, increasing risks of compression and fragmentation.

Furthermore, Zhengzhou's location in the transitional zone of the middle and lower Yellow River basin renders its ecological baseline fragile. Factors such as abnormal climate patterns, frequent droughts, and intensified urban heat island effects have led to vegetation degradation and water body shrinkage, significantly reducing ecosystem stability. The severe rainstorm event on July 20 exposed the inadequacy of urban ecological buffering capacity, with the hardening of wetlands and farmland further impairing ecosystem resilience and adaptability. Structural adjustments in industry, including the rapid emergence of high-end manufacturing, emerging industrial parks, logistics hubs, and science and education parks, have extensively occupied former grasslands, forests, and water bodies, altering ecological node distribution, weakening connections among core green infrastructure zones, and diminishing overall functional efficiency.

In response, urban renewal and ecological restoration initiatives have been progressively implemented, including "urban double repair," pocket parks, street green spaces, and vertical greening projects. These measures have enriched the diversity of green infrastructure patches, increasing Shannon diversity and evenness indices, and enhancing landscape heterogeneity. However, such patch-based greening efforts primarily serve as localized repairs and are insufficient to replace large-scale, continuous ecological corridors. Consequently, they are limited in their capacity to fundamentally mitigate landscape fragmentation and connectivity decline.

5. Conclusion

The findings of this study indicate that from 2015 to 2025, the total area of green infrastructure (GI) within the Jialu River Basin in Zhengzhou has experienced a continuous decline, with a significant contraction of core ecological source areas. The number of patches (NP) and landscape shape index (LSI) have increased, while the contagion index (CONTAG) has decreased, reflecting an escalating degree of landscape fragmentation and diminishing aggregation. Concurrently, although key connectivity elements such as bridge zones and ring roads have shown localized increases, overall stability remains compromised, with an increasing proportion of isolated patches, leading to a decline in landscape connectivity. These patterns collectively suggest that the GI network in the study area is undergoing pronounced degradation under the pressures of rapid urbanization, thereby threatening ecological security patterns. The spatiotemporal dynamics are primarily driven by urban expansion, land resource pressures, fragile ecological baselines, climate change, industrial restructuring, and localized ecological restoration projects, among multiple interacting factors.

This research offers valuable methodological and practical insights for future studies in this domain. Methodologically, it validates the combined application of MSPA (Morphological Spatial Pattern Analysis) and landscape pattern indices as effective tools for assessing changes in urban GI network structure and health status, providing a replicable technical framework for similar regional analyses. Practically, it elucidates the key points and driving mechanisms of ecological degradation in the Zhengzhou Jialu River Basin, offering precise scientific evidence and direct decision-making support for managers to identify priority ecological spaces for protection and restoration, such as core areas and critical corridors.

Future research should focus on the following directions for in-depth exploration: First, integrating land use change simulation models (e.g., FLUS, CA-Markov) and dynamic early warning systems for ecological security patterns to predict and simulate the evolution of GI networks under various urban development scenarios, thereby enhancing planning foresight. Second, strengthening the quantitative analysis of socio-cultural drivers (e.g., policy frameworks, public participation) to comprehensively reveal the underlying causes of GI changes. Lastly, future studies could further incorporate ecosystem service valuation and circuit theory models to not only assess structural connectivity but also quantitatively evaluate functional connectivity and the flow and demand of multiple ecosystem services, facilitating a transition from “pattern optimization” to “functional enhancement” and supporting the development of more resilient urban-rural ecological networks.

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