URBAN GREENSPACE MORPHOLOGY IN SMALL CITIES: A MULTI-DIMENSIONAL ASSESSMENT FROM CHINA'S LIXIAHE REGION

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Abstract. The importance of urban greenspace in achieving sustainable development is widely acknowledged, yet assessments of UGM (urban greenspace morphology, UGM) remain underexplored, particularly in small cities. This study examined seven small cities in China's Lixiahe region, which share similar developmental levels but exhibit varying greenspace conditions. A comprehensive six-dimensional assessment framework was developed, integrating urban morphology and landscape ecology. Spatial analyses using FRAGSTATS and ArcGIS revealed significant morphological differences among the cities, with Dongtai scoring highest (73.17% high-level areas) and Xinghua lowest (12.53%). High-level UGM areas were predominantly concentrated in the urban fringes, decreasing toward city centers, indicating a gradient in distribution. Quantitative results showed minor differences in compactness and connectivity, but greater variation in fragmentation and evenness. Grey correlation analysis further demonstrated a significant relationship between UGM scores and the proximity of greenspaces to the water system morphology, with cities showing closer ties to water systems achieving higher rankings. Based on these findings, the study proposes targeted optimization strategies for each city. This research contributes novel perspectives and methodologies for UGM assessment and optimization, offering practical guidance for rational and effective planning, construction, and management of urban greenspaces.
Keywords: *comprehensive evaluation, morphological assessment, landscape metrics, comparative study, urban greenspace optimization*

Introduction

Two-thirds of the global population will reside in urban areas by 2050 (United Nations, 2022). Urbanization contributes to economic growth, industrial advancement, and social development. However, it also brings about ecological challenges, including air pollution (Wang et al., 2020), water contamination (Foley et al., 2005; Zhao et al., 2013), the urban heat island effect (Zhang et al., 2009), and the depletion of biodiversity (Aronson et al., 2014; MacGregor-Fors et al., 2016). As the sole spatial entity endowed with natural attributes within the built environments (Boulton et al., 2018; Taylor and Hochuli, 2017), UG (urban greenspaces, UG) play a pivotal role in enhancing environmental quality and maintaining the ecological balance (Semeraro et al., 2021; Wang, 2007).

Although the protection and expansion of UG have become a consensus among managers and planners, the goal of achieving inclusive, safe, and accessible greenspaces for all on limited urban land still faces many practical dilemmas (Haaland and van den Bosch, 2015; United Nations, 2015), especially in terms of the equitable distribution of greenspaces and the protection of their ecological benefits. Empirical studies show that when greenspace coverage ratios drop below 40%, ecological benefits are primarily influenced by internal configuration and spatial distribution patterns (Zhou et al., 2004). In

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this context, optimizing the UGM (urban greenspace morphology, UGM) has transcended mere quantitative expansion, emerging as the critical pathway for ameliorating urban environments, ensuring environmental justice, and advancing sustainable urban development (Lu et al., 2024; Pezzagno et al., 2021; Zhang and Qian, 2024).

UGM, as a hybrid system of natural and artificial elements, has attracted significant scholarly attention recently. Current studies predominantly adopt two methodological frameworks. The morphological perspective examines UG's "form," "distribution," and "pattern," emphasizing spatial planning methodologies. In contrast, the ecological approach conceptualizes UG as green infrastructure, analyzing their configuration and matrix impacts on urban ecosystems (Zou and Wang, 2021).

Urban morphological studies underpin effective landscape planning and stewardship, with methodologies widely applied in practice (Hall, 2013; Oliveira et al., 2014). Compared to artificial elements like architecture and street networks, natural components as UG remain under-investigated in urban morphology, often ambiguously defined through terms like "green areas" or "gardens," which have limited quantitative analytical frameworks. Although space syntax has been utilized for UG accessibility analysis, these tools inadequately capture UG's ecological and environmental attributes (Ye et al., 2019). Early scholarship prioritized greenspaces in urban fringe belts (Hopkins, 2012; Whitehand and Morton, 2004). Recent advances have noted UG in urban central areas, such as a structural analysis of the Çağlayan District in North Nicosia, revealing the multi-scalar distribution of UG and their morphogenetic relationships with built forms (Kahouei, 2022). And a diachronic study of 26 fortified towns found that the greenspaces inside the city walls historically served defensive and agricultural functions while contemporaneously providing irreplaceable ecological regulation, social cohesion, and cultural heritage conservation values (Scitaroci and Maric, 2019). Nevertheless, predominant micro-scale studies at plot or neighborhood levels lack macro-scale syntheses, failing to inform city-scale planning practices.

UGM is a crucial research area in urban landscape ecology, emphasizing the unique "network" structure composed of greenspace "patches" and "corridors" (Ignatieva et al., 2011). A large number of studies have analyzed the structural characteristics of UG, mainly focusing on the dynamic changes of UGM (Zhang et al., 2019; Zhao et al., 2024), the driving mechanisms of the evolution of UGM (Dallimer et al., 2011; Feng et al., 2024), and the impact of UGM on urban ecological processes (Liu et al., 2023b; Zhang et al., 2023).

Landscape metrics serve as quantitative descriptors, have proven instrumental in characterizing greenspace structural attributes (Safzadeh, 2023), assessing the degree of fragmentation of UG (Tian et al., 2014) and analyzing the differences among various forms of UG in mitigating urban heat islands, enhancing hydrological cycles, and improving air quality (Liu et al., 2022; Masoudi and Tan, 2019; Wang et al., 2022a; Wu et al., 2024). Most studies have been conducted at the city scale, focusing on large and medium-sized UG (parks, greenways, etc.) and neglecting affiliated greenspaces, including street-side plantings and residential courtyard vegetation. The metrics focus more on the greenspace itself and do not involve the analysis of the relative relationship between other artificial elements and greenspaces. Despite substantial advancements in understanding morphology-environment interactions, implementation gaps persist between academic insights and planning applications (Zhu and Shi, 2021). Current decision-making remains predominantly guided by fiscal priorities and aesthetic valuations rather than evidence-based morphological optimization principles.

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Future research should integrate urban morphology with landscape ecology to construct a unified framework for studying UGM, thereby strengthening the application of theoretical insights to planning practice. Although scholars have thoroughly discussed this integration at the theoretical level (Marcus et al., 2019), there is still a shortage of applied studies. Optimizing the UGM is based on a comprehensive evaluation of their current conditions. Existing assessment studies predominantly focus on aesthetic quality, ecosystem service provision, accessibility, and equity (Duan et al., 2025; Knobel et al., 2021; Zhang et al., 2020). Despite being relatively limited, urban-scale evaluations from a morphological aspect are essential. We believe that the goal of UGM research is to identify optimal greenspace forms through interdisciplinary analysis, enabling practical optimization that enhances the efficiency of greenspace configurations. This approach seeks to maximize the use of limited urban space to create ecologically sustainable and livable environments.

UG has undergone significant changes in China, including quantitative contraction, accelerated fragmentation, and increased spatial heterogeneity (Chen et al., 2017; Lin et al., 2021). Following the implementation of territorial spatial planning and the ecological prioritization strategy, China's greenspace is expanding rapidly (Jin et al., 2019). The national average UG rate has increased from below 15% to 39% (MOHURD, 2023), leading to significant environmental improvements. However, this growth has caused an overemphasis on quantitative instead of rational spatial configuration (Wang, 2009), especially in small cities. In China, a small city is which with an urban resident population size of less than 500,000 people (State Council of China, 2014). In the early stages of urban development with ample space, these cities often prioritize planning formats over functionality in their greenspace systems planning, which can undermine ecological effectiveness (Liu, 2010). Despite these challenges, research focusing on small cities remains relatively underdeveloped. Given their numerical predominance, the morphological rationality of their greenspaces directly impacts a more significant number of residents' quality of life and regional sustainable development (Delgado-Serrano et al., 2024). Therefore, conducting comprehensive morphological assessments to identify specific deficiencies and formulate operational optimization strategies for small cities has become an urgent planning priority.

Evaluating UGM at the city scale is of great theoretical and practical significance for the in-depth understanding of the overall ecological and environmental functions of urban natural space as well as guiding urban planning and construction (Zou and Wang, 2021). This study integrated urban morphology and ecology research from the perspective of planning practice, referring to the framework of urban open space morphology "quantity - spatial distribution - functional pattern" (Wang, 2007). A quantitative analysis framework was constructed for UGM, focusing on six dimensions—Dominance, Connectivity, Compactness, Evenness, Fragmentation, and Complexity. This study aims to examine the development and construction of greenspaces in small cities and propose more targeted optimization strategies according to the different characteristics of urban greenspaces.

Materials and methods

Study area

The Lixiahe region (32° 25′N-34° 07′N, 119° 08′E-120° 56′E), located in central Jiangsu Province (*Fig. 1)*, is a typical plains river network region characterized by

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higher around the perimeter and lower in the center, with 80.2% of the region having an elevation below 3 meters, making it one of the lowest-lying areas in China (Jiang et al., 2024). This unique topography results in gentle slopes and a dense network of waterways. The climate is transitional between subtropical and warm temperate zones, with an average annual temperature of 14-15°C, an average annual rainfall of 1000 mm, and an evaporation of 960 mm (Huang et al., 2008; Sun et al., 2021). Seven small cities were selected, more details are provided in *Table 1*. The seven cities are comparable in scale and economic development. They are facing analogous challenges in balancing urban development and ecological preservation during the urbanization process. Analyzing the morphological characteristics of urban greenspaces in these cities enables comparative analysis, revealing commonalities and differences in UGM. This process helps identify general rules and influencing factors, offering valuable insights for green space planning and development in similar small cities.

Table 1. *Basic information of 7 cities in the Lixiahe region*

City	Study area (km^2)	Urban population	UGS coverage	Proportion of water	Average elevation (m)
Jianhu (JH)	75.88	378759	27.86%	7.62%	2
Baoying (BY)	58.89	391839	22.60%	6.63%	2
Xinghua (XH)	56.99	318636	20.61%	16.80%	1.8
Gaoyou (GY)	61.10	307255	33.29%	8.81%	0.85-4.8
Dongtai (DT)	55.78	332745	33.16%	8.59%	4
Jiangyan (JY)	62.75	331452	33.36%	3.97%	2.8-3.7
Haian (HA)	91.55	454639	33.13%	4.52%	4-5

Sources: population data was from China's seventh population census; average elevation data was from each city's official government website; the other data were obtained from aerial photography measurements

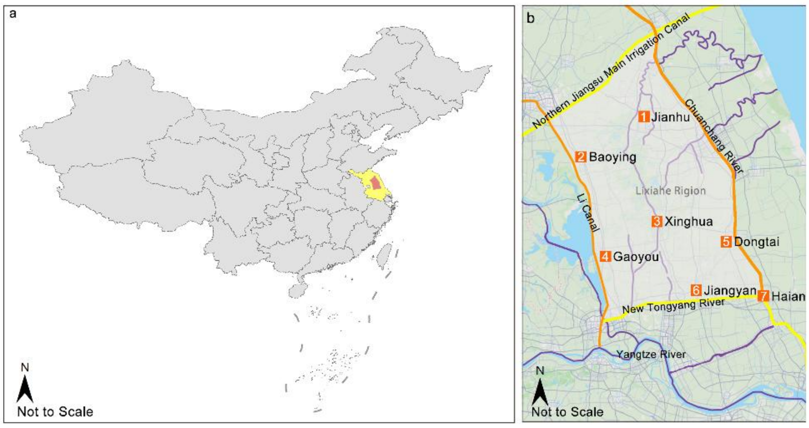

Figure 1. *(a) Location of Lixiahe region in China. (b) Location of seven cities*

The concept of urban boundaries has not yet been standardized, common definitions in research including administrative and urban development boundaries. However, these definitions often fall short for comparative studies since they are based on administrative management. Research indicates that morphological boundaries provide

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greater comparability and consistency in describing greenspace morphology than administrative and buffer boundaries (Taubenbock et al., 2021). Consequently, this study defined the urban area as a spatially continuous and relatively dense built-up space, delineating each city's research scope accordingly (*Fig. 2*).

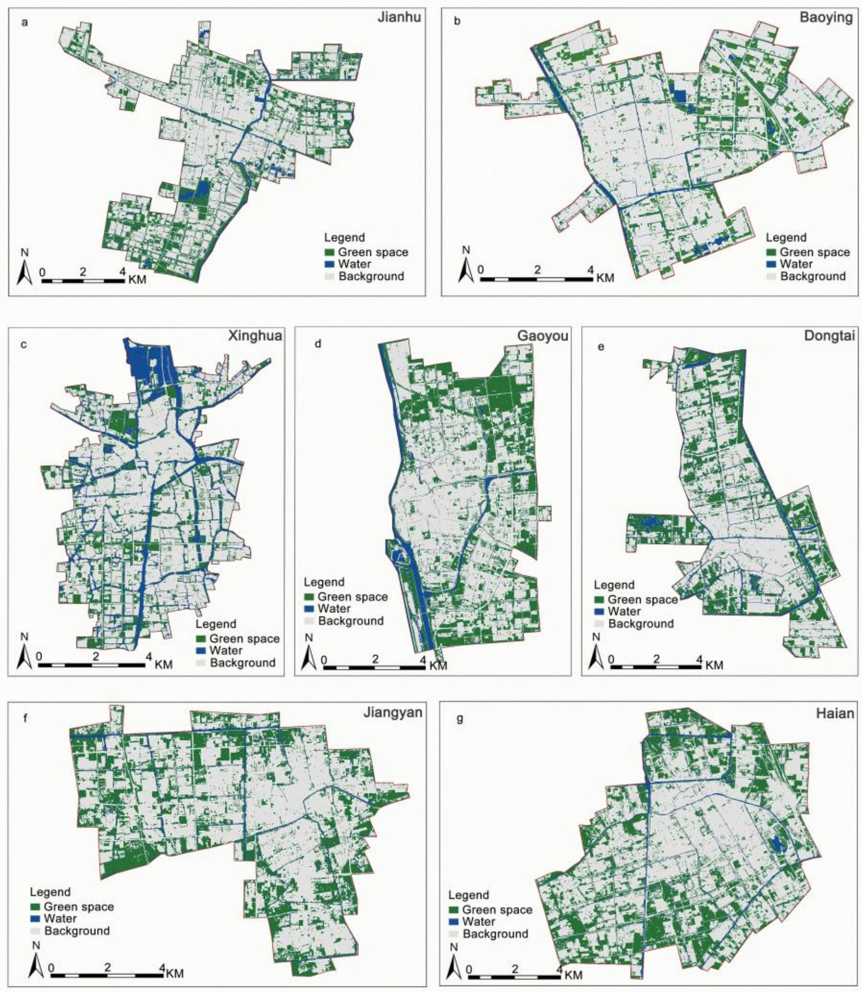

***Figure 2.** Urban greenspaces of 7 cities in the Lixiahe region*

Research framework

The research framework comprised four components (*Fig. 3*). Initially, a spatial information database of greenspaces in the Lixiahe region was established using high-resolution remote sensing images and Google Earth data. Subsequently, an evaluation system based on six dimensions was constructed with nine indexes identified through screening. Next, UGM was evaluated, and a comparative analysis was conducted to identify characteristics and derive rankings. Finally, optimization strategies were proposed based on each city's unique circumstances.

Mapping UGM based on high-resolution imagery

The data were derived from four view GF remote sensing images (*Table 2*), collected during peak vegetation growth in August and September 2020, facilitating accurate

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classification. Using ENVI 5.3 software, the raw images underwent pre-processing steps and were clipped by urban morphological boundaries. The greenspace information was extracted using the NDVI (Normalized Difference Vegetation Index, NDVI), with thresholds for each city determined by referencing Google Earth imagery with repeated corrections (*Table 3*). Extracted greenspaces were cross-verified against Google Earth imagery and each city's greenspace system planning maps to correct misclassifications. According to *China's urban greenspace classification standards (CJJ/T85-2017),* any greenspaces smaller than 100 m², the minimum area for a pocket park, were excluded.

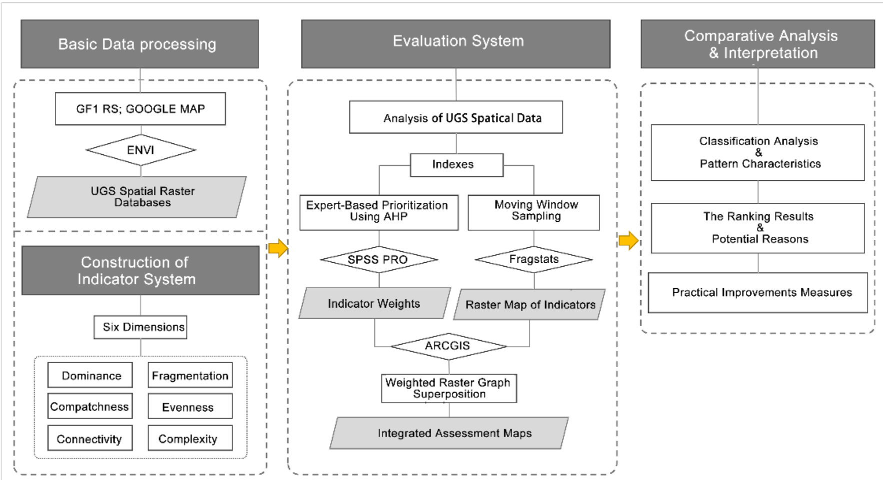

Figure 3. *The flow chart of the research process*

Table 2. *Basic information of original images*

Numbers	Product type	Acquisition time	Cloud cover	Cover cities	Resolution
1	GF1-B/PMS	05-09-2020 11:29:06	5%	GY, BY, XH	2 m
2	GF-1B/PMS	03-08-2020 11:24:54	1%	JH	2 m
3	GF-1D/PMS	18-08-2020 11:05:19	1%	DT	2 m
4	GF-1D/PMS	18-08-2020 11:05:28	1%	HA, JY	2 m

Table 3. *Calculation method and threshold of NDVI*

Calculation formula	Thresholds						
$NDVI = \frac{NIR^* - R^*}{NIR + R}$	JH	BY	XH	GY	DT	JY	HA
	0.45	0.42	0.50	0.60	0.50	0.45	0.45

NIR* represents the near-infrared band, and R* denotes the red band. R and NIR correspond to Band 2, 3, and 4 values of the GF-1 image

Quantification of UGM

Selection of indicators

Urban greenspace is characterized by quantity, morphology, and spatial distribution (Xu et al., 2019). This study evaluated the UGM in six dimensions: Dominance,

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Connectivity, Compactness, Evenness, Fragmentation, and Complexity. For precise assessment, seven landscape metrics and two evenness indices were utilized (Yin, 2008). The extensive application of these landscape metrics has clarified their ecological significance, and we tried to elucidate their planning implications further. (*Table 4,* the calculation formulas in *Appendix Schedule 1*)

Table 4. *Selection of the landscape pattern index and the significance*

Dimensions	Metrics	Description and significance
Dominance	PLAND	The percentage of the UG (PLAND). The greater, the higher the habitat and species diversity, leading to an enhanced provision of ecosystem services and a more significant role in ecological functions. PLAND directly indicates the development level of greenspaces in planning practice and is one of the most frequently utilized metrics
	LPI	The percent of the landscape that the largest patch comprises (LPI). The larger the LPI is, the greater the degree of advantage of greenspace in the city and the greater the influence of the most significant green space. In planning, it reflects the degree of advantage of large parks in the city
	PD	The number of patches per unit area (PD). The dual nature of PD requires judgment based on context, overlaid maps of greenspace distribution, and patch density to assess overlaps between high patch density and low green coverage in this study. In this study, high patch density corresponded with a relatively high proportion of green coverage, indicating a positive aspect in the overall evaluation
Connectivity	COHENSION	The CONHENSION index (CON) measures greenspace connectedness, indicating the aggregation and dispersion of greenspace patches. Higher values suggest better natural connectivity among patches, which aids organism migration and organic matter flow. From a planning perspective, increased connectivity promotes accessibility and equity
Compactness	ENN_MN	The average of the shortest straight-line distance between the focal patch and its nearest neighbor (ENN_MN). The smaller the value, the closer the average distance between greenspaces is, the more compact the distribution, and the higher the degree of aggregation
Evenness	ER	ER was built based on SHEI and used to quantify the degree of evenness of urban greenspace spatial distribution in the orientation and concentric annulus system. A low ER ratio signifies that the distribution of greenspaces across the eight directions or each concentric layer exhibits minimal disparity. As this ratio approaches zero, it indicates a more balanced allocation of greenspaces, facilitating equitable access to green space services for residents
Fragmentation	SPLIT	SPLIT equals the total landscape area (m^2) divided by the sum of patch area (m^2) squared, summed across all patches of the greenspace. SPLIT can represent the distribution structure of greenspace areas. The larger the value, the smaller the greenspaces are, and the more fragmented the overall area is, with poorer continuity and integrity
Complexity	LSI	The landscape shape index (LSI) provides a standardized measure of total edge or edge density that adjusts for the size of the landscape. LSI $\geqslant$ 1, without limit. The greater the value, the more intricate the shape of the patch, leading to a more pronounced edge effect and a more significant impact on species. In planning contexts, this metric can indicate the degree of compatibility between greenspace and other land uses. A higher value signifies a greater level of integration

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Standardized methodology

Because of the index system encompasses both positive and negative indicators with significantly different value ranges, it is essential to dimensionless and standardize the original scores of these indicators. This study employed the Min-Max normalization method to ensure all indicators align with the principle that a higher value signifies better UGM. Positive indicators include PLAND, LPI, PD, COHESION, and LSI, while negative indicators comprise ENN_MN, SPLIT, ER_CIR, and ER_DIR. The calculation formula is as follows:

$$X_{+} = (x - \min)/(\max - \min); X_{-} = (\max - x)/(\max - \min) \quad \text{(Eq.1)}$$

where X + means positive indicators, X- means negative indicators.

Comprehensive evaluation method

Determination of weights: analytic hierarchy process

Each evaluation criterion for UGM has a unique value, but their relative importance can vary, influencing the fairness and accuracy of outcomes. Achieving precise measurement through purely quantitative methods is challenging and under-researched. This study utilized the AHP with expert scoring to determine criterion weights, leveraging the extensive knowledge of ten experts (details in *Appendix Schedule 3*), meeting the AHP's statistical validity requirements for small to medium-expert groups (Ramer et al., 2019). Based on their discussions, a pairwise comparison judgment matrix was created (*Table 5*), with a CR (Consistency Ratio, CR) below 0.1, confirming consistency. The final weights are detailed in *Table 6*.

Table 5. *Pairwise comparison between indicators*

Indicator	Dominance	Connectivity	Compactness	Evenness	Fragmentation	Complexity
Dominance	1	1.111	1.25	1.429	1.667	2
Connectivity	0.9	1	1.111	1.25	1.429	1.667
Compactness	0.8	0.7	1	1.25	1.667	2.5
Evenness	0.7	0.8	0.8	1	1.429	2
Fragmentation	0.6	0.7	0.6	0.9	1	1.667
Complexity	0.5	0.6	0.7	0.6	0.8	1

CR = 0.004

Table 6. *Final index weight*

First-level indicators	Weight	Second-level indicator and weight	Final weight
Dominance	22.20%	PLAND (0.6)	13.30%
		LPI (0.2)	4.40%
		PD (0.2)	4.40%
Connectivity	20.26%	CON (1)	20.30%
Compactness	17.64%	ENN_MN (1)	17.60%
Evenness	15.71%	ER_DIR (0.5)	7.85%
		ER_CIR (0.5)	7.85%
Fragmentation	13.13%	SPLIT (1)	13.10%
Complexity	11.05%	LSI (1)	11.10%

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Spatial characterization and superposition methods

The linear weighting method is widely used for comprehensive evaluation, which is done by multiplying normalized values of indicators by their weights to derive a final score. However, this approach can obscure critical spatial characteristics in urban studies. To address this, the study combines the weighting and overlay methods, using FRAGSTATS and ArcGIS to create superimposed comprehensive raster maps for evaluating UGM. The final result is based on the space occupation of each grade and its score.

When using FRAGSTATS moving window sampling, it is crucial to balance the window size to retain sufficient detail while capturing overall features. This study calculated the average pixel values for window sizes between 100 m and 1000 m and found that pixel values stabilized at 500 m, which was selected as the optimal window size for analysis.

The raster maps generated by FRAGSTATS need to be reclassified to standardize the score intervals to a range of 1-5, where a higher score indicates better UGM. The SPLIT values vary significantly among different areas; however, the raster maps produced in FRAGSTATS show slight variation. To better represent the differences between the cities, this study recalibrated the values for all pixels within the study area based on the magnitude of the SPLIT value for each city (*Table 7*). Then, the raster calculator function in ArcGIS was used to weigh and overlay the reclassified maps, resulting in a comprehensive morphological evaluation of the raster map. The calculation formula is as follows:

$$S_{UGM} = 0.133*PLAND + 0.044*LPI + 0.044*PD + 0.203*CON + 0.176*ENN\_MN \\ +0.079*(ER\_DIR + ER\_CIR) + 0.131*SPLIT + 0.111*LSI \quad \text{(Eq.2)}$$

where SUGM means the comprehensive evaluation results of UGM.

Finally, comprehensive raster maps of each city were reclassified into five grades: poor, fair, average, good, and best, corresponding to a score of 1-5. The proportion of each grade was calculated and multiplied by the corresponding score to determine the final score and ranking.

***Table 7.** Reclassification results of split values*

City	Original SPLIT Value	Reclassification value
JH	1372.63	3
BY	2017.91	2
XH	4880.98	1
GY	449.43	5
DT	563.89	5
JY	684.07	4
HA	796.56	4

Grey relational analysis

GRA (Grey Relational Analysis, GRA) can measure the correlation between system elements by comparing the similarity of data sequence sets and curve shapes (Zhou and

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Zeng, 2020). It has been widely used in urban planning research (Gao et al., 2022; Li and Wang, 2018; Yi et al., 2021). This study employs GRA to explore the correlation between UGM indicators and the morphological complexity of the water system, with the analysis conducted using SPSS PRO software (SPSSPRO, 2021).

Results

Quantitative results on UGM

The quantitative results of the UGM were shown in *Table 8*. Among all the indicators, the CV (coefficients of variation, CV) for ENN_MN and CON were the smallest, while SPLIT was the largest. The remaining indicators exhibited moderate variability. This means that the compactness and connectivity among the seven cities' greenspaces differ slightly. At the same time, there were more pronounced variations in other dimensions, fragmentation and evenness varied most.

Table 8. *Results from FRAGSTATS with no sample model*

City	PLAND	LPI	PD	SPLIT	ENN_MN	CON	LSI	ER_DIR	ER_CIR
JH	27.86%	1.23	41.70	1372.63	21.81	98.14	89.60	1.64	6.53
BY	22.60%	0.89	38.32	2017.91	28.60	97.63	64.25	2.12	4.38
XH	20.61%	0.73	55.43	4880.98	23.94	96.13	80.68	0.92	2.58
GY	33.29%	3.25	44.58	449.43	24.32	98.4	62.17	2.87	5.08
DT	33.16%	2.38	39.60	563.89	25.52	98.48	59.12	1.18	9.71
JY	33.36%	1.81	39.29	684.07	26.17	98.43	62.02	1.35	3.50
HA	33.13%	1.88	39.99	796.56	25.52	98.40	77.48	1.51	5.72
Mean value (MV)	29.14%	1.74	42.70	1537.92	25.13	97.94	70.76	1.63	4.76
Coefficient variation (CV)	0.19	0.51	0.14	1.02	0.08	0.01	0.17	0.39	0.44

Regarding Dominance (*Fig. 4a*), JY, GY, DT, and HA exhibited similar high PLAND scores, while JH, BY, and XH scored significantly lower. The LPI value among cities showed significant variation, with GY achieving the highest score and XH the lowest. For the PD, except for XH and GY, the remaining cities had relatively low and similar scores. GY excelled overall in Dominance, while XH and BY performed poorly. Regarding Fragmentation and Connectivity (*Fig. 4b*), most cities scored high with minor differences, except JH, BY, and XH. Specifically, GY performed best in Fragmentation and DT in Connectivity, while XH ranked lowest. Contrary to the ranking pattern of other indicators, JH and XH scored higher in Compactness and Complexity, while DT and JY scored low (*Fig. 4c*). For Evenness (*Fig. 4d*), DT achieved the highest scores in ER_CIR and ER_DIR, while JH and HA scored the lowest in these metrics, respectively.

In summary, there are notable differences in UGM across seven cities in the Lixiahe region. GY stood out for its high scores in Dominance and Fragmentation, indicating a strong presence of greenspaces, although their distribution is somewhat fragmented. In contrast, DT performed well in Connectivity and Evenness, suggesting it has a well-connected and evenly distributed greenspace network. JH and BY had high scores in Complexity and Compactness, indicating diverse shapes and a dense arrangement of greenspaces. Lastly, XH showed a weak performance in most indicators, suggesting a pressing need for improvement in its greenspace management.

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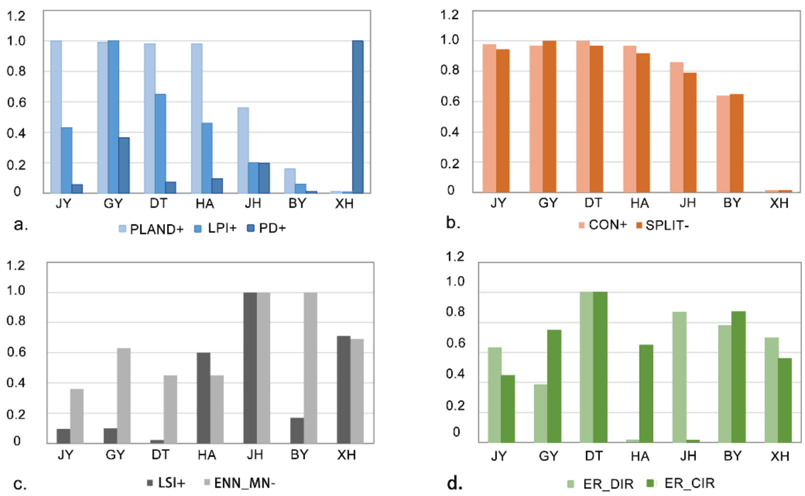

***Figure 4.** Normalized index value chart. (a) Dominance. (b) Connectivity and fragmentation. (c) Complexity and compactness. (d) Evenness. +/- means the indicators after normalization*

Comprehensive evaluation results

The spatial distribution maps for each index (*Appendix Schedule 5*) were superimposed based on weight, generating the comprehensive score raster map (*Fig. 5*), which forms the foundation of the final evaluation. The spatial ratio of high- and low-level areas provided the basis for the ranking (*Table 9*).

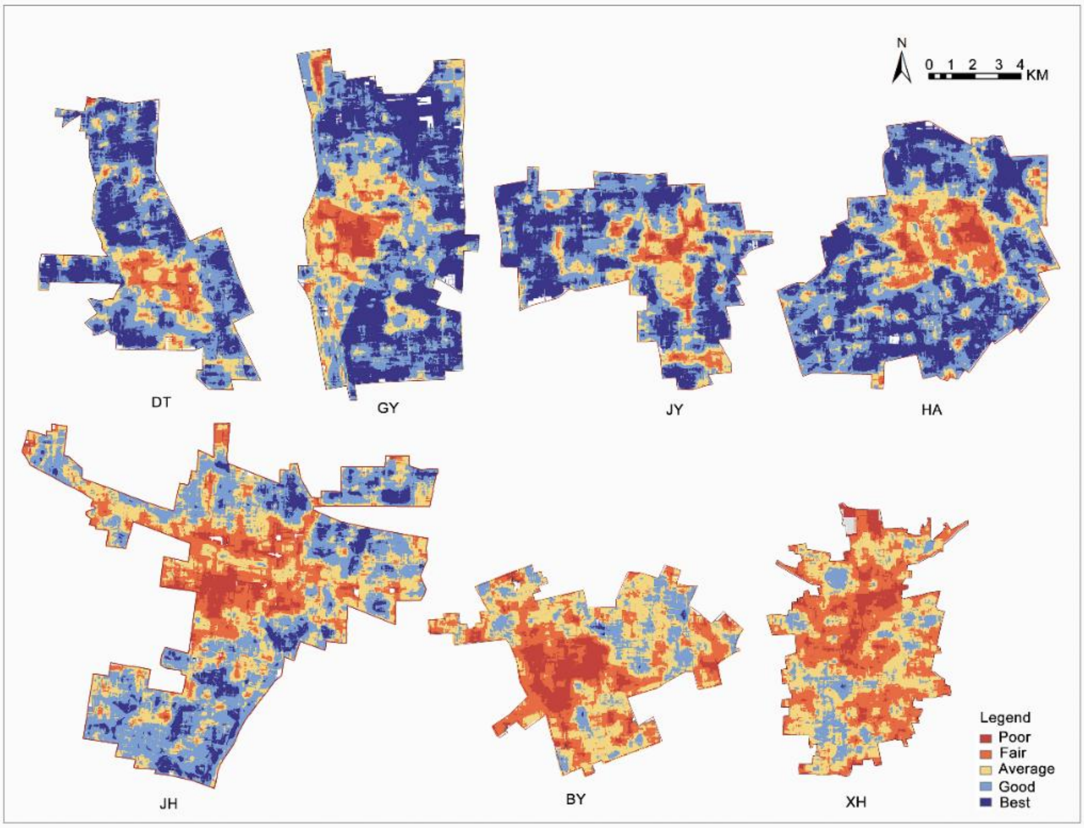

***Figure 5.** Graph of comprehensive evaluation score*

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Table 9. *Statistics on the proportion of each grade for each city*

Grade	Score	JH	BY	XH	GY	DT	JY	HA
Poor	1	5.09%	13.61%	9.42%	3.04%	1.19%	1.82%	2.59%
Fair	2	17.55%	31.71%	40.96%	6.74%	7.35%	7.48%	9.21%
Average	3	29.89%	38.91%	37.10%	21.05%	18.29%	21.56%	18.06%
Good	4	37.58%	15.44%	12.48%	32.82%	39.08%	35.11%	34.96%
Best	5	9.89%	0.33%	0.05%	36.36%	34.09%	34.03%	35.18%
Final score		3.2963	2.5717	2.5281	3.9275	3.9753	3.9205	3.9093
Ranking		5	6	7	2	1	3	4

The low level in this study means poor and fair grades and the high level means good and best grades

The results indicated that HA, JY, GY, and DT exhibit significant advantages in UGM. Specifically, DT ranked highest with a high-level area proportion (HLP) of 73.17%, demonstrating that most areas within the city have an excellent greenspace composition and spatial structure. HA, GY and JY had similar HLP values, with GY placing second at 36.36%. Although HA had a slightly higher HLP than JY, it also carried a more significant low-level area proportion (LLP), ranked fourth and JY third.

In contrast, JH, BY, and XH ranked lower in the overall evaluation of UGM, with significantly fewer high-level areas than the other four cities. JH performed slightly better with an HLP of 45% but still ranked fifth. BY ranked sixth, with only 15.77% of its regions achieving better grades, while 13.61% received the grade Poor. XH ranked last, with merely 12.53% of its areas classified as high-level.

Despite considerable variations in the spatial proportion of different grades among cities, a discernible pattern emerged in their spatial distribution. Low-level areas were concentrated in city centers, whereas high-level areas were predominantly found at the periphery of urban built-up areas. This created an apparent gradient that transitions from lower values in the centers to higher values towards the periphery.

Spatial pattern of UGM grades and their internal characteristics

The spatial distribution of Grade Poor and Best areas was systematically extracted across all cities, with subsequent analysis of their internal respective greenspace attributes (detailed data refer to *Appendix Schedules 2* and *3*). Except XH and BY, the number and area of Grade Best areas in the other cities significantly exceed those of Grade Poor. This suggests that most cities in the Lixiahe region exhibited a favorable development trend, with high-quality UGM predominant.

A comparison of the overlap between the Grade Poor areas in each city and the boundaries of old city districts (as referenced from Google Maps circa 2005) showed that more than half of the cities had an overlap exceeding 50%. Specifically, HA showed a high overlap of 93%, while BY had the lowest at 39%. In contrast, areas classified as "Grade Best" are predominantly located in the urban fringes or emerging development zones.

Statistical results of the characteristics of greenspace within or surrounding the Grade Poor showed that the distribution of greenspace in Grade Poor areas across all cities (*Fig. 6a*) was broadly consistent. The proportion of internal greenspace was generally less than 21%. In most cases, it accounted for less than 10%. As the proportion of greenspace increases, the quantity tended to decrease. This trend corresponded to the

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presence of fragmented, small patches of greenspace that were widely dispersed or, in some cases, completely absent. There were only a few sporadic small greenspaces around the periphery.

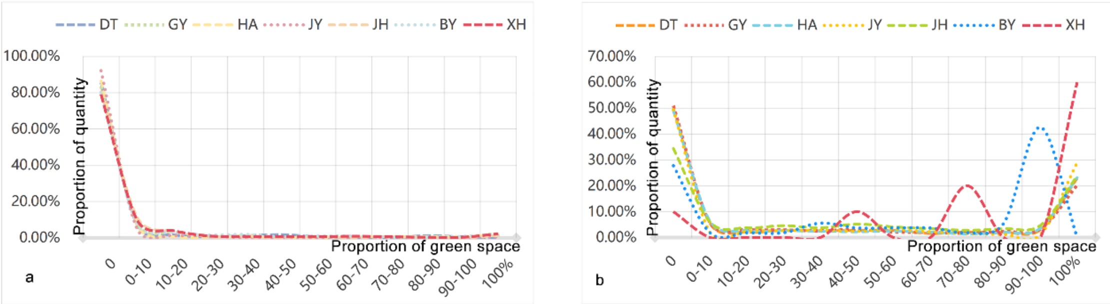

***Figure 6.** Statistical chart of greenspace proportion distribution. (a) Grade poor area. (b) Grade best area*

The distribution of internal greenspace in Grade Best areas varied slightly (*Fig. 6b*). All cities, except XH, have over half of Grade Best areas featuring greenspace. Generally, the highest frequency corresponded to 0% greenspace, followed closely by 100%, while proportions between 20% and 30% were third. In BY, the highest frequency was for greenspace proportions of 90-100%, and in XH, it was 100%, both exceeding 40%. These patterns differed in BY and XH, likely due to smaller sample sizes.

Result of grey relational analysis

The result of GRA (*Fig. 7*) showed that, UGM was closely related to watershed morphology characteristics. Except LPI and PLAND, there was a relatively close correlation between the greenspace morphology indicators and the morphological complexity of the watershed.

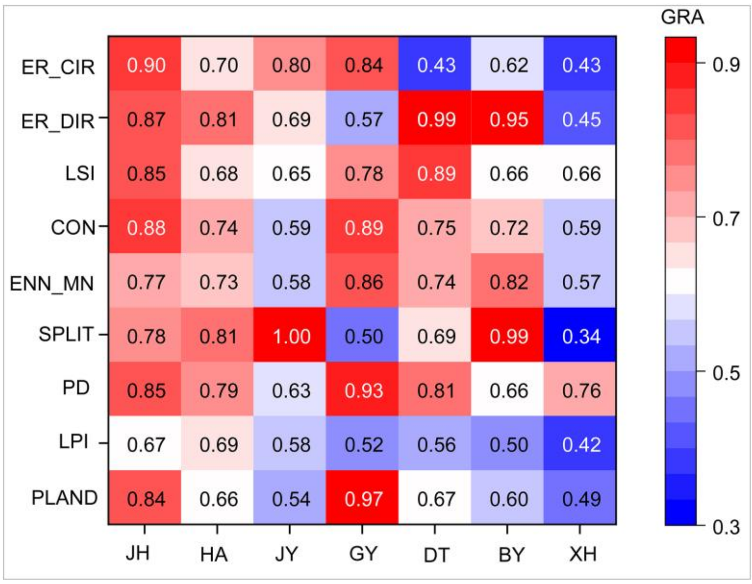

***Figure 7.** GRA results of UGM and complexity of water system morphology*

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Moreover, the results indicated that, a notably stronger relationship between UGM and water system complexity in JH, GY, and HA, whereas in XH and JY, this relationship was comparatively weaker. Preliminary observations (*Table 10*) suggested that cities with lower comprehensive evaluation rankings often had watersheds with more enormous proportions and complex patterns.

Table 10. *Basic information of urban water system of 7 cities in the Lixiahe region*

City	Proportion	Complexity	Rankings
JH	7.62%	55.64	5
BY	6.63%	65.81	6
XH	16.80%	77.58	7
GY	8.81%	55.16	2
DT	8.59%	36.18	1
JY	3.97%	21.86	3
HA	4.52%	35.57	4

Discussion

Spatial characteristics and distribution of UGM in small cities

The comprehensive evaluation of UGM assessed the spatial characteristics and elucidated spatial differences within these small cities. The result of UGM analysis showed little difference in compactness and connectivity but significant differences in fragmentation. All cities showed distinct features across the six dimensions. Although previous studies have suggested that small cities tend to have a more defined spatial axis in their green space distribution, with greenspaces often aligned along main roads, rivers, or other linear features, contrasted with the more intricate and fragmented patterns seen in larger cities (Jia et al., 2019). This study further revealed that UGM exhibited distinctive characteristics among small cities and should not be simplistically portrayed as less complex than those in larger cities.

When examining the spatial distribution, areas achieving worse grades were primarily concentrated in city centers, better grades are predominantly located in the urban fringes or emerging development zones. The predominant type of greenspace in urban center was affiliated greenspace, which comprised 25-40% of urban centers (Jin and Xu, 2023). However, these greenspaces were primarily concentrated in certain residential areas, businesses, universities, and government complexes, leading to insufficient public access and low utilization efficiency (B. Liu et al., 2023). Other studies on the distribution of urban greenspaces have also obtained similar results. Greenspace is highly fragmented in urban centers, consisting mostly of small patches with complex shapes and high density (Li et al., 2019; Zhou et al., 2018).

Areas achieving better grades usually in the urban fringes, featuring large internal greenspaces or continuous connections to surrounding ones, the main types of green spaces are parks and protective green spaces, forming continuous greenbelts. Despite being less numerous, these greenspaces are essential, covering larger areas, supporting richer vegetation, and providing diverse ecological functions (Li et al., 2023). Although larger and more continuous greenspaces are found in the urban fringes, but these areas are also experiencing increasing fragmentation as urbanization expands outward (Yang et al., 2018; Zhou et al., 2024).

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Influencing factors and optimization approaches

Two common potential factors underlie the morphological shortcomings of these urban greenspaces. One is the lack of coordination between the greenspace layout and the morphological features of the water system. The result of GRA suggested that when UGM and the morphology of water systems are closely correlated, cities are more likely to achieve better scores in comprehensive evaluations. This result highlights the importance of coordinating urban greenspaces with water system forms, aligning with prior studies that indicate urban greenspaces and water systems are inseparable and intertwined (Jiao et al., 2023; K. Wang et al., 2022). The phenomenon can be attributed to the fact that more complex water system morphology tends to subdivide urban plots, which increases the number of greenspace patches and affects patch density. The complexity of the urban water system can also enhance the irregularity of greenspace patches, leading to increased shape complexity (Wang et al., 2022b). Additionally, a more complex water system may promote a more even distribution of greenspaces in all directions.

In the future, urban planning in the Lixiahe region should closely integrate the characteristics of the water system and fully utilize the city's river network by arranging linear greenspaces. This approach can enhance the currently low ratings in central urban areas and establish a blue-green space network with regional characteristics.

Another common potential factor is temporal effect of urban development. The decreasing trend of UGM evaluation results from the periphery towards the city center is likely to associated with the sequence of planning and construction. It is influenced by the urban planning concepts and greenspace construction standards prevalent in different periods. Typically, the central areas of cities have an earlier development history. During that era, functionalism played a dominant role in urban construction, the primary urban functions were residential, commercial, and industrial, land use was highly intensive, and greenspaces were frequently treated as elements to fill in the remaining spaces, showing a fragmented distribution (Wang et al., 2025). These central areas face significant challenges in optimizing UGM due to historical factors and limited space (Dickinson, 2019). The later "filling" renewal model of greenspace will also intensify this situation.

Urban fringe areas, which include low-density road networks, large, well-vegetated parcels, and a clear zoning trend in morphology (Whitehand and Morton, 2004). In addition to these features, urban fringes are also characterized by abundant natural resources, lower development intensity, and later construction phases. They benefit from scientifically sound and later reasonable greenspace planning, robust urban construction regulations, and meticulous greenspace management, all of which contribute to the protection and expansion of greenspace, resulting in higher quality (Chen et al., 2022). Many small cities are still in expansion as they continue to develop. This means that the current urban edges are likely to become soon central. Continuous urban expansion can lead to unstable urban fringe areas (Angel, 2023). To prevent the continued formation of low-level UGM in central areas, it is crucial to prioritize the protection of greenspaces during the development and construction of urban fringe (Cui et al., 2020; Liu et al., 2020).

A key strategy for achieving sustainable development is to utilize greenspaces within these areas to create habitat patches, connect greenspaces both within and outside the city, and establish a comprehensive network (Wang, 2023). Specific measures to accomplish this include identifying valuable greenspaces, implementing fine

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management based on high-resolution data, and aligning with higher-level statutory plans such as territorial spatial and greenspace planning. These actions aim to ensure effective protection and morphological control of greenspaces in marginal areas, similar to the well-known London Green Belt Circle (Amati and Yokohari, 2006).

Contributions and shortcomings

A comprehensive evaluation of UGM is vital for effective urban planning. This study presented a new evaluation framework that integrates weighting and overlay mapping methods. It addressed the shortcomings of traditional linear approaches by preserving the complexity of greenspace spatial features. This study selected small cities in the Lixiahe region, characterized by similar scales and geographical conditions, as research samples for horizontal comparison. It aims to fill the current gap in analyzing greenspace morphology in small cities. The methodology of this study can serve as a reference for many small cities worldwide, especially when assessing UGM from a valid perspective when data are limited. The study was also crucial for achieving fine-grained greenspace management, exploring the mechanisms that generate UGM, optimizing the functional layout of greenspace, promoting innovation in greenspace planning methodologies, enhancing urban ecological quality, and fostering balanced regional development.

Although this study has made progress in the comprehensive evaluation of UGM, certain limitations remain. When constructing the evaluation index system, efforts were made to ensure comprehensiveness by including as many relevant dimensions as possible. This approach may lead to high correlations between some indicators, potentially affecting the accuracy of the analysis (Uuemaa et al., 2013). While avoiding correlation between metrics is generally important, it is relatively minor compared to the necessity of comprehensively capturing all urban greenspace features (Coppedge et al., 2001). In this study, it is more critical to include all meaningful indicators for a comprehensive evaluation to avoid omitting effective features.

This study employed a ranking method to comprehensively evaluate the advantages and disadvantages of UGM in different cities. Rankings are effective for quickly identifying positioning and gaps within these evaluations, especially when dealing with objects that are difficult to assess using absolute numbers (Taubenbock et al., 2021). However, it is essential to note that subjective factors can influence rankings. Thus, it is crucial to use ranking tools carefully and acknowledge that while subjective perceptions can be minimized, they cannot be entirely eliminated.

Establishing a universally recognized standard for UGM assessment remains challenging. This study represented a significant exploration in this field, trying to expand the application scope of the landscape metrics and promote further investigation and improvement of UGM assessment methods.

Conclusion

Based on the optimization of UGM in the context of rapid urbanization, this study developed a comprehensive evaluation system by integrating urban morphology and landscape ecology research methods. Seven small cities in Lixiahe region are selected as samples, aiming to reveal the divergent characteristics of UGM and to propose more targeted and operational optimization strategies.

The results indicated significant differences in UGM in several dimensions, particularly in fragmentation and evenness. GY excelled in dominance and fragmentation, DT stood out in connectivity and evenness, while XH ranked poorly in most indicators. The spatial comprehensive evaluation revealed that most cities exhibit high-level UGM, with DT ranking first and XH at the bottom. The spatial distribution of the same scores was concentrated and demonstrated a gradient, shifting from low to high from the center to the urban fringe. In low-level areas, there are scattered small patches distanced from each other or a few small greenspaces nearby. In contrast, high-level areas contain much larger greenspaces or are closely connected to surrounding greenspaces. The predominant type of greenspace in the low-level areas is affiliated greenspace and in high-level areas are parks and greenbelts. In addition to identifying problems of UGM in each city, this study also found that all cities lack morphological integration between greenspace and water system, which may be one of the main reasons for the generally low ratings of urban centers.

In summary, this study provided new perspectives and methods for assessing and optimizing UGM, which has important theoretical and practical significance for the greenspace planning and management.

The study of small cities in China demonstrated the complexity and diversity of UGM in the stage of rapid urban development and provided a unique sample for international research as well as a reference for other developing countries. Moving forward, it is essential to improve the assessment methods of UGM by constructing a more objective evaluation system, and introduce more international samples for validation, so as to improve the accuracy and universality.

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APPENDIX

Schedule 1. *Actual greenspace in grade poor area*

Dimensions	Metrics and computational formula
Dominance	$PLAND = \frac{\sum_{j=1}^{n} a_{ij}}{A}(100\%)$
	$LPI = \frac{\max(a_{ij})}{A}(10)$
	$PD = \frac{n_i}{A}$ a_{ij} = Area of patch ij; A = total landscape area; n_{ij} = number of greenspace patches
Connectivity	$CON = \left[1 - \frac{\sum_{j=1}^{n} P_{ij}^*}{\sum_{j=1}^{n}\sqrt{a_{ij}^*}}\right] \cdot \left[1 - \frac{1}{\sqrt{Z}}\right]^{-1} \cdot (100)$ p_{ij}* = perimeter of patch ij in terms of several cell surfaces; a_{ij}* = area of patch ij in terms of several cells; Z = total number of cells in the landscape
Compactness	$ENN\_MN = \frac{\sum_{j=1}^{n} h_{ij}}{N}$ p_{ij}* = perimeter of patch ij in terms of several cell surfaces; a_{ij}* = area of patch ij in terms of several cells; Z = total number of cells in the landscape
Evenness	$ER^* = \sum_{j=1}^{n}\left\|R_{ij}\right\| = \sum_{j=1}^{n}\left\|\ln(\frac{a_j}{a_i} / \frac{A_j}{A})\right\|$ R_{ij} = evenness ratio of urban greenspace in sector j or circle j; a_j = total area of urban greenspace in Sector j or Circle j (m^2); a_i = total area of urban green space (m^2); A_j = area of sector j or circle j (m^2); n = number of sectors or circles
Fragmentation	$SPLIT = \frac{A^2}{\sum_{j=1}^{n} a_{ij}^2}$ a_{ij} = area (m^2) of patch ij; A = total landscape area (m^2)
Complexity	$LSI = \frac{0.25E^*}{\sqrt{A}}$ E* = total length (m) of edge in the landscape; includes the entire landscape boundary and some or all background edge segments; A = total landscape area (m^2)

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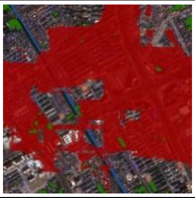
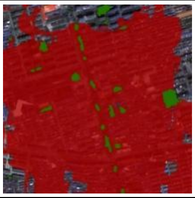
Schedule 2. *Actual greenspace in grade poor area*

City	Quantity and area	Proportion	Representative district	Overlap rate with the old city
DT	A total of 173 plots, 64.72hm^2			77.23%
	No greenspace inside (148 plots)	85.55%		
	Greenspace inside (25 plots)	14.45%		
GY	A total of 169 plots, 181.88hm^2			82.47%
	No greenspace inside (141 plots)	83.43%		
	Greenspace inside (28 plots)	16.57%		
JY	A total of 204 plots, 113.13hm^2			53.07%
	No greenspace inside (176 plots)	86.27%		
	Greenspace inside (28 plots)	13.73%		
HA	A total of 288 plots, 234.08hm^2			93.05%
	No greenspace inside (249 plots)	86.46%		
	Greenspace inside (39 plots)	13.54%		
JH	A total of 415 plots, 381.04hm^2			48.62%
	No greenspace inside (334 plots)	80.48%		
	Greenspace inside (81 plots)	19.52%		
BY	A total of 646 plots, 791.67hm^2			39.39%
	No greenspace inside (515 plots)	79.72%		
	Greenspace inside (131 plots)	20.28%		
XH	A total of 687 plots, 526.42hm^2			49.42%
	No greenspace inside (543 plots)	79.04%		
	Greenspace inside (144 plots)	20.96%		

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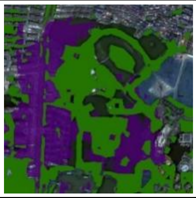
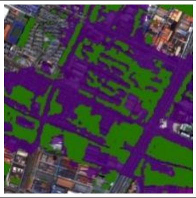
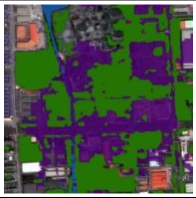
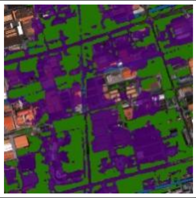
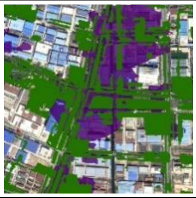
Schedule 3. *Actual greenspace in the grade best area*

<table>
<tr><th>City</th><th>Quantity and area</th><th>Proportion</th><th>Representative district</th></tr>
<tr><td rowspan="3">DT</td><td colspan="2">A total of 1900 plots, 1868.16hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (948 plots)</td><td>49.89%</td></tr>
<tr><td>Greenspace inside (952 plots)</td><td>50.11%</td></tr>
<tr><td rowspan="3">GY</td><td colspan="2">A total of 1878 plots, 2177.30hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (924 plots)</td><td>49.20%</td></tr>
<tr><td>Greenspace inside (954 plots)</td><td>50.80%</td></tr>
<tr><td rowspan="3">JY</td><td colspan="2">A total of 1582 plots, 2113.67 hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (782 plots)</td><td>49.43%</td></tr>
<tr><td>Greenspace inside (800 plots)</td><td>50.57%</td></tr>
<tr><td rowspan="3">HA</td><td colspan="2">A total of 2281 plots, 1642.61hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (885 plots)</td><td>38.80%</td></tr>
<tr><td>Greenspace inside (1396 plots)</td><td>61.20%</td></tr>
<tr><td rowspan="3">JH</td><td colspan="2">A total of 849 plots, 740.18hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (292 plots)</td><td>34.39%</td></tr>
<tr><td>Greenspace inside (557 plots)</td><td>65.61%</td></tr>
<tr><td rowspan="3">BY</td><td colspan="2">A total of 54 plots,19.08hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (15 plots)</td><td>27.78%</td></tr>
<tr><td>Greenspace inside (35 plots)</td><td>72.22%</td></tr>
<tr><td rowspan="3">XH</td><td colspan="2">A total of 10,2.81hm^2</td><td rowspan="3"></td></tr>
<tr><td>No greenspace inside (8 plots)</td><td>80%</td></tr>
<tr><td>Greenspace inside (2 plots)</td><td>20%</td></tr>
</table>

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Schedule 4. *Details of experts*

Name	Institutions	Positions
Tang Jun	Southeast University	Associate Professor, Senior Architect, Certified Planner
Zhang Guanting	Nanjing University of Technology	Lecturer
Zou Hao	Nanjing University of Technology	Lecturer, Landscape Architect
Sun Tianzhi	Anhui University of Arts	Lecturer
Wei Xiao	Xi'an University of Architecture and Technology	Postdoctor
Xu Ruofei	Architectural Design and Research Institute of Southeast University	Senior Landscape Architect
Liu Xinyu	Zhejiang University	Postdoctor
Chen Xin	Southeast University	Ph.D Candidate
Zhuang Xuntong	Southeast University	Ph.D Candidate
Wu Zhigao	Southeast University	Ph.D Candidate

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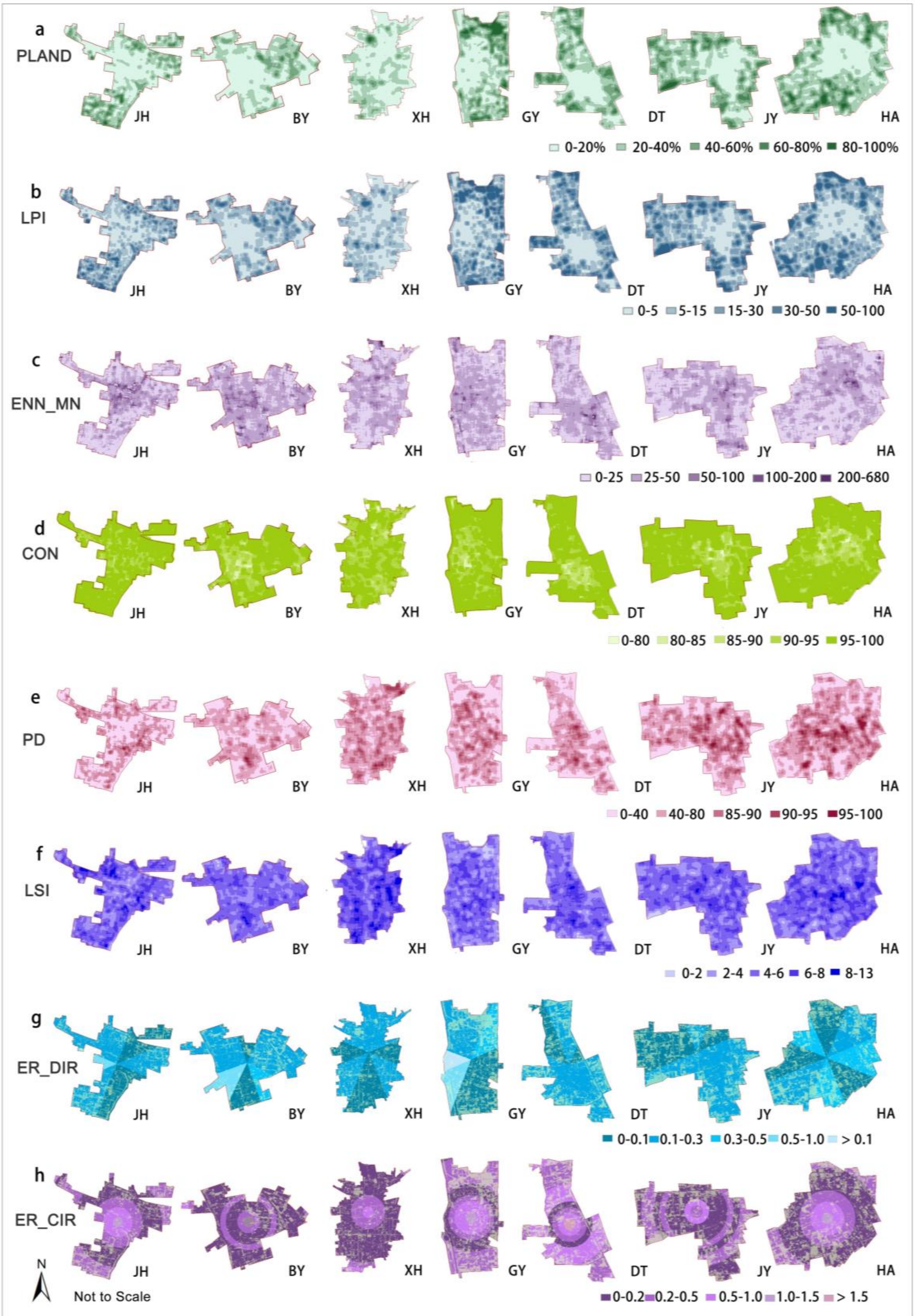

***Schedule 5.** Spatial distribution figures of indicators*

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