Research Paper

Assessment and optimization of urban blue-green space services based on multi-source big data: A case study of central Wuhan

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Abstract

Rapid urban development has exacerbated urban problems, creating an urgent need for systematic assessment of blue-green spaces as the ecological foundation, to enhance residents' well-being and guide sustainable development. Focusing on the primary functions of ecology and recreation for measuring urban blue-green space services, we selected six dimensions with twelve indicators. Using central Wuhan as a case study, we integrated diverse data sources and applied game theory to evaluate services and propose targeted optimization strategies. The results indicate that ecological attributes dominate the service scores of urban blue-green spaces, directly influencing overall rankings. The service capacity of blue-green spaces in central Wuhan exhibits a polarized distribution, with high and low service capacity spaces accounting for 41% and 36%, respectively, while moderate service capacity spaces accounting for 23%. Based on the evaluation results, the lowest-scoring Zhuyehai Park was selected as a typical site for further analysis, and optimization recommendations were made using the service measurement framework to improve external connectivity and restore ecological diversity. This study employs a data-driven dual evaluation of ecological and recreational service functions to provide practical evaluation criteria and solutions for multi-objective urban environmental planning.

Keywords

Urban blue-green space, Service function, Assessment framework, Multi-source big data

1. Introduction

Urbanization is a prominent global trend, with over 55% of the world's population currently living in cities (United Nations, 2019). The rapid development of urban areas has led to increasingly prominent problems that hinder sustainable development (Sharifi, Nygaard and Stone, 2021). Urban water systems are shrinking, and water shortages are becoming increasingly severe (Nouri, Chavoshi Borujeni and Hoekstra, 2019). At the same time, urban water bodies have experienced significant pollution and degradation, contributing to the heightened risk of flooding in some cities (Wu *et al.*, 2024). Urban blue-green spaces, especially lake parks at the intersection of urban water and green systems, provide both ecological and recreational service. These spaces contribute significantly to human well-being and life quality (Knight, McClean and White, 2022; Zhou, Cen and Qiu, 2023). Therefore, a comprehensive study and application of urban blue-green spaces is urgently needed.

Key sustainability characteristics are central to measuring service functions (Li *et al.*, 2017; Ricci, 2022). Although some progress has been made in recent years, the potential for synergy between urban green and blue remains underexplored. Moreover, appropriate theoretical frameworks for service measurement and practical tools for assessment are still lacking (Kimic and Ostrysz, 2021; Ye and Qiu, 2021; Jiao *et al.*, 2023). Wuhan, a city with abundant water resources along the Yangtze River, has blue-green spaces play an important role in urban environment (Zhu and Zeng, 2018). Assessing the service capacity of blue-green spaces in the central Wuhan may provide valuable insights for the planning and sustainability enhancement of urban blue-green spaces.

This research aims to develop a service measurement framework for urban blue-green spaces, focusing on two primary service types: ecological and recreational. We employed multi-source big data, integrating geographic information, web data, and field surveys, to perform a multi-scale, hierarchical assessment of service functions. Through game theory, we weighted and integrated measurement dimensions to comprehensively evaluate the service functions of urban blue-green spaces in Wuhan. Based on this, we provided optimization recommendations for typical parks, offering theoretical support for blue-green space development with targeted strategies for ecological and recreational enhancement.

2. Methods

2.1. Study area

Wuhan (29°58′– 31°22′ N, 113°41′–115°05′ E), a megacity in central China with a permanent population exceeding 10 million, has a northern subtropical monsoon climate and is located in the eastern part of the Jianghan Plain. Its flat, low-lying terrain features extensive lakes and waterways, earning it the nickname “City of a Hundred Lakes”. In 2023, the Wuhan Municipal Bureau of Forestry and Parks (https://ylj.wuhan.gov.cn/) reported 38 lakes in central Wuhan, distributed over 12 water systems. There are 23 lakes already developed into parks or squares, creating 22 blue-green spaces (Figure 1, Table 1).

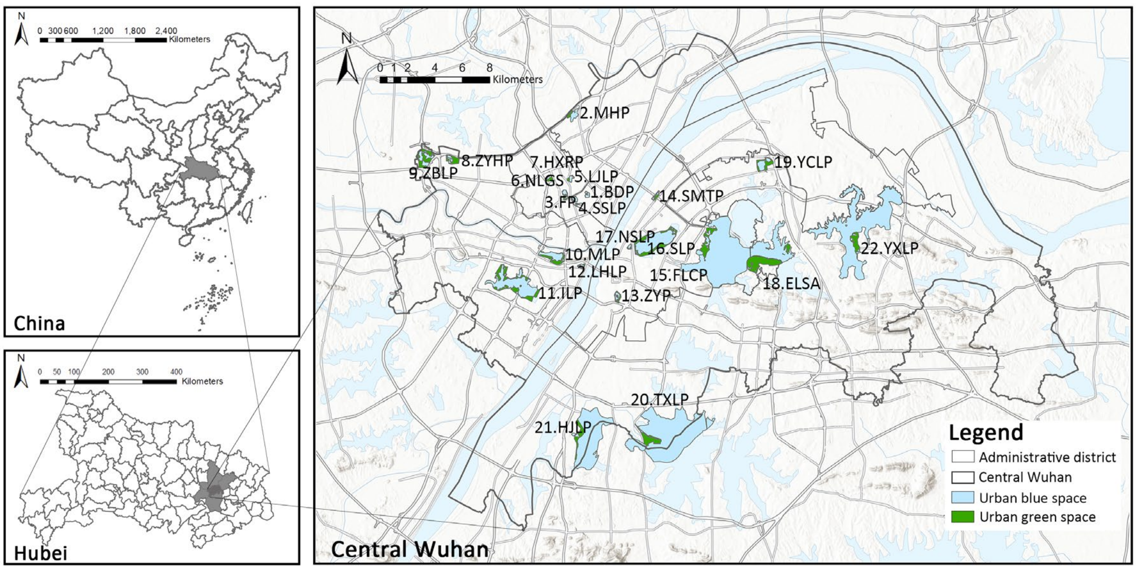

Figure 1. Distribution of 22 blue-green spaces in central Wuhan. Source: Wuhan Goverment, 2014

According to the Lake Protection Plan of Wuhan Government, based on the primary functions and specific characteristics of Wuhan's blue-green spaces, they can be classified into two main categories: ecological spaces and recreational spaces (Table 1). Recreational blue-green spaces are primarily located in the Jiang'an, Jianghan, and Wuchang districts, while ecological blue-green spaces are concentrated in the Qiaokou, Hanyang, and Hongshan districts, reflecting the current urban development trends in Wuhan.

Table 1. Selected blue-green spaces in central Wuhan and theirs functional positioning. Source: Wuhan Goverment (2014)

No.	Location	Water Body	Completed Park	Tag in Figure 1	Functiona
1	Jiang'an District	Wanzi Lake	Baodao Park	BDP	Recreational
2		Tazi Lake	Menghu Park	MHP	Recreational
3		Jiqidangzi	Fountain Park	FP	Recreational
4		Small South Lake	Small South Lake Park	SSLP	Recreational
5	Jianghan District	Lingjiao Lake	Lingjiao Lake Park	LJLP	Recreational
6		West Lake	Northwest Lake Green Square	NLGS	Recreational
7		Houxiang River	Houxiang River Park	HXRP	Recreational
8	Qiaokou District	Zhuyehai	Zhuyehai Park	ZYHP	Ecological
9		Zhangbi Lake	Zhangbi Lake Park	ZBLP	Ecological
10	Hanyang District	Moon Lake	Moon Lake Park	MLP	Ecological
11		Ink Lake	Ink Lake Park	ILP	Ecological
12		Lianhua Lake	Lianhua Lake Park	LHLP	Recreational
13	Wuchang District	Ziyang Lake	Ziyang Park	ZYP	Recreational
14		Simaitang	Simaitang Park	SMTP	Recreational
15		Fruit Lake	Fruit Lake Children's Park	FLCP	Recreational
16		Waisha Lake	Sha Lake Park	SLP	Recreational
17		Neisha Lake	Neisha Lake Park	NSLP	Recreational
18	Hongshan District	East Lake	East Lake Scenic Area	ELSA	Ecological
19		Yangchun Lake	Yangchun Lake Park	YCLP	Ecological
20		Tangxun Lake	Tangxun Lake Park	TXLP	Ecological
21		Huangjia Lake	Huangjia Lake Park	HJLP	Ecological
22		Yanxi Lake	Yanxi Lake Park	YXLP	Ecological

2.2. Framework for Measuring Blue-Green Space Services

Urban blue-green spaces provide both ecological and recreational services, these functions emphasize the environmental and social benefits of blue-green space services (Knobel, Dadvand and Maneja-Zaragoza, 2019; Ye and Qiu, 2021). We integrated findings from relevant studies on blue-green space services, utilizing ecosystem service classifications, spatial landscape dimensions, and hierarchical construction methods. Indicators reflecting the characteristics and functions of blue-green spaces were incorporated to establish evaluation criteria. Ecological service criteria include landscape connectivity, stormwater retention, and plant diversity (Andersson-Sköld *et al.*, 2018; Arthur and Hack, 2022; Wu *et al.*, 2024), while recreational service criteria encompass service area, spatial layout, and service quality (Lahoti, Lahoti and Saito, 2019; Liu and Xiao, 2021; Sharifi, Nygaard and Stone, 2021; Roberts, Glenk and McVittie, 2022). Finally, a service evaluation system based on multi-source data was developed, comprising 2 types, with 6 categories totaling 12 indicators (Figure 2).

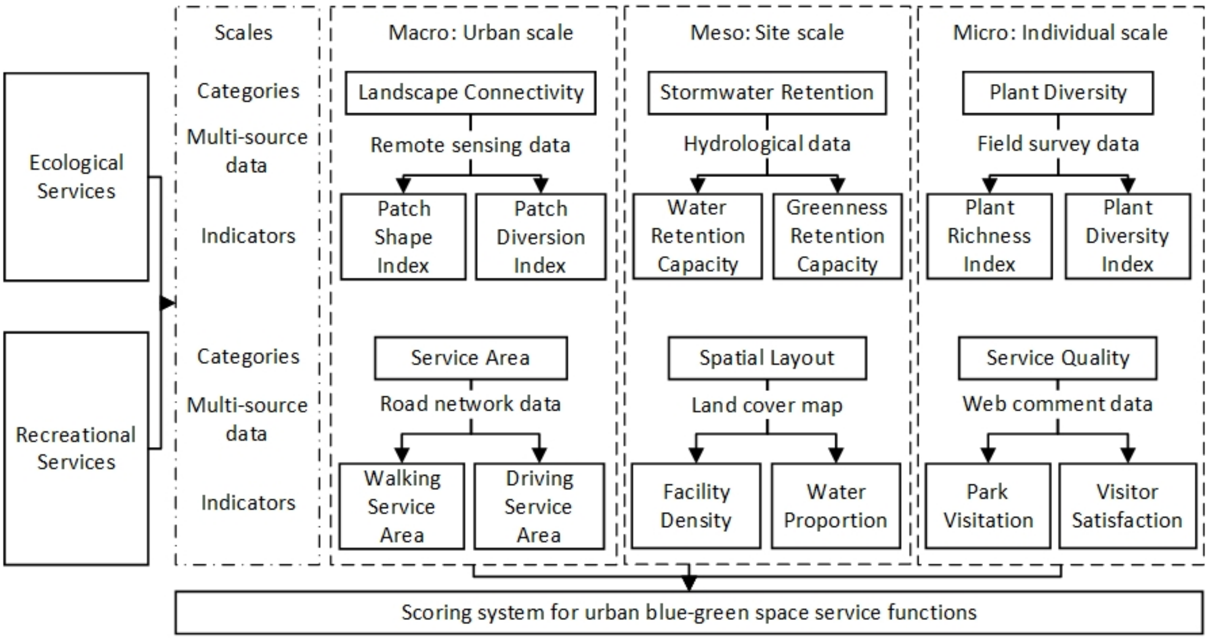

Figure 2. Evaluation framework for measuring blue-green space services. Source: Author Analysis, 2024

2.3. Measurement of Blue-Green Space Service Functions

2.3.1 Ecological Services of Blue-Green Spaces

Landscape connectivity is a critical indicator for assessing landscape structure and function, reflecting how the landscape supports or obstructs ecological flows. Using ArcGIS, lake data were extracted and imported into Fragstats software to quantify the connectivity of blue-green spaces. Two key indicators were selected to assess connectivity: the Shape Index (*SI*) which measures patch irregularity, and the Division Index (*D*) measures spatial fragmentation:

$$SI_i = P_i/minP_i$$

$$D_i = L_i/S_i$$

where P_i is the perimeter of patch *i*, and $minP_i$ is the perimeter of a circle with the same area as patch *i*. The distance index for patch *i*, L_i is calculated as $Li = \frac{1}{2}\sqrt{n/A}$, the area proportion of patch *i* is given by $S_i = A_i/A$, where *n* is the total number of all patches, *A* is the total study area, and A_i is the area of patch *i*.

To assess the stormwater retention capacity of blue-green spaces, 30-meter resolution ASTERG DEM data were used, along with field surveys and elevation data obtained from Google Earth. Hydrological analysis tools in ArcGIS were used to delineate rainfall runoff paths and lake catchment areas. The SWMM model was used to simulate surface runoff in Wuhan, calculating the water retention capacities of water bodies (V_0) and green spaces (V):

$$V_0 = (H_s - H_0)S$$

$$V = 10H_r\varphi F$$

where H_S is the design high water level, H_0 is the normal water level, and S represents the surface area of the water body. H_r is the design rainfall of the water body, φ is the runoff coefficient, and F represents the catchment area.

A sample-based method was used to analyze the distribution of aquatic plants along the waterfront and to assess the diversity of the plant communities. The species composition and growth patterns of aquatic plants in Wuhan's blue-green spaces were evaluated, and characteristic plant communities were identified. The study focused on biodiversity, assessing species richness with the Margalef Index and species diversity using the Shannon-Wiener Diversity Index.

2.3.2 Recreational Services of Blue-Green Spaces

To evaluate the recreational services provided by urban blue-green spaces, the primary focus is on the service area available to city residents. ArcGIS was used to create a spatial database of blue-green spaces. Road network integration (*I*) within a specified radius of each park, along with distance from the city center (*DTC*), was used to calculate walking and driving service areas. The relative asymmetry of nodes was calculated using the average shortest paths between each node and others, yielding the integration value *I*, which reflects connectivity and accessibility within a given radius. The higher the *I* value, the better the walkability and accessibility of the service area:

$$M\bar{D} = \left(\sum_{d=1}^{s} dN_d\right)/(n - 1)$$

$$RA = 2(M\bar{D} - 1)/(n - 2)$$

$$I = 1/RA$$

where $M\bar{D}$ represents the average depth, d is the shortest angular path between nodes, N_d is the number of paths at a given depth, and n is the total number of intersection nodes. RA refers to the relative asymmetry, and its reciprocal is taken to ensure a positive correlation with the integration value I.

With respect to the mesoscale layouts, Points of Interest (POIs) serve as critical data points for understanding the intensity of public activity and the rationality of the distribution of facilities within these spaces. A web scraping tool was used to collect POI data for Wuhan's central urban area from Baidu Maps, and the number of POIs within each park was counted in ArcGIS 10.7. Density calculations were performed to show the concentration of facilities. The proportion of water bodies refers to the ratio of water area to the total park area within urban blue-green spaces, which indicates the water attractivenes. Land use data for Wuhan were collected and calculated the ratio of water to park area.

Park service quality was assessed using visitor data, focusing on visitation numbers and satisfaction levels. Web-based information was collected to analyze the recreational service levels of blue-green spaces. Data was obtained from the review website (https://www.dianping.com/), using a web scraper to collect the number of reviews and star ratings for each park between April 2017 and September 2019. The total number of reviews reflected the popularity and visitation levels of each park, while star ratings ranged from 1 to 5, with 5 stars indicating very high satisfaction and 1 star indicating dissatisfaction.

2.4. Combined Weighting Based on Game Theory

Indicator weighting methods typically include subjective, objective, and combined approaches (Li, Fan and Shen, 2018). Subjective weighting relies on the judgment of decision makers, while objective weighting uses the data-driven methods (Chen *et al.*, 2020; Ye and Qiu, 2021). As a whole, Each method has its advantages and disadvantages: subjective methods are influenced by human biases, while objective methods may deviate from common understanding. Game theory, often used in multiobjective decision making (William, Garg and Stillwell, 2017), was applied here to integrate the entropy method and analytic hierarchy process (AHP) for combined weighting. Entropy-based weights were optimized with expert input to ensure a more objective and reasonable evaluation of urban blue-green space services.

AHP was used to construct a pairwise comparison matrix from the expert ratings. Geometric means and row normalization provided the priority vector, which was aggregated into a comprehensive weight vector. A consistency test ensured the reasonableness of the expert judgments and adjustments were made where necessary. The entropy method was also applied to calculate the value coefficient for each indicator to derive the individual weights. This process involved normalizing raw data to remove unit influence, then calculating entropy and variation to determine final indicator weights. Finally, game theory was used to integrate the subjective and objective weights (Table 2).

Table 2. Indicator weights for the evaluation system based on combined weighting. Source: Data Processing Results, 2024

Goals	Projects	Criterions	Indicators	AHP Weight	Entropy Weight	Combined Weight
Blue-Green Space Service Function	Ecological Services	Landscape Connectivity	Patch Shape Index	0.04	0.10	0.07
			Patch Diversion Index	0.06	0.13	0.09
		Stormwater Retention	Water Retention Capacity	0.12	0.15	0.14
			Greenness Retention Capacity	0.11	0.21	0.16
		Plant Diversity	Plant Richness Index	0.10	0.02	0.06
			Plant Diversity Index	0.07	0.03	0.08
	Recreational Services	Service Area	Walking Service Area	0.06	0.02	0.04
			Driving Service Area	0.03	0.02	0.02
		Spatial Layout	Facility Density	0.05	0.15	0.10
			Water Proportion	0.06	0.03	0.05
		Service Quality	Park Visitation	0.09	0.15	0.12
			Visitor Satisfaction	0.14	0.01	0.07

Given the varying scales, dimensions, and indicators, using raw values to analyze blue-green spaces in the central urban area would overemphasize indicators with higher values and underemphasize those with lower values. To address this, the commonly used z-score normalization method (Chen *et al.*, 2021) was applied to standardize the data and calculate th urban blue-green space service functions. ChatGPT (OpenAI, 2024) was used to assist in language improvement during the writing process.

3. Results

3.1. Overall Blue-Green Space Service Functions in Wuhan

3.1.1 Overall Service Function Scores

Using multi-source big data in the service function calculation model, scores for 22 urban blue-green spaces in Wuhan were calculated (Table 3).

Table 3. Service scores of blue-green spaces in Wuhan. Source: Data Processing Results, 2024

Rank	Urban Blue-Green Space	Synthesis Score	Evaluation Grade
1	Yanxi Lake Wetland Park	3264.12	High
2	East Lake Scenic Area	3149.28	
3	Tangxun Lake Wetland Park	227.98	
4	Fruit Lake Children's Park	207.68	
5	Small South Lake Park	128.80	
6	Ink Lake Park	61.98	
7	Shahu Park	53.99	
8	Neishahu Park	23.47	
9	Lingjiaohu Park	16.79	
10	Ziyanghu Park	6.16	Medium
11	Huangjiahu Wetland Park	-3.71	
12	Xibeihu Green Plaza	-5.28	
13	Baodao Park	-7.55	
14	Yangchunhu Ecological Park	-8.21	
15	Houxiang River Park	-15.99	Low
16	Simetang Park	-17.75	
17	Moon Lake Park	-21.77	
18	Zhangbihu Park	-24.45	
19	Fountain Park	-28.27	
20	Lianhuahu Park	-31.38	
21	Menghu Park	-39.73	
22	Zhuyanghai Park	-43.16	

In total, 10 parks scored above average and 12 scored below average. The distribution of synthesis score is relatively uniform, except for the two highest. The median value serves as the rating standard, defining the middle range of scores as -4.5 ± 11.38. High score parks make up 41% (9 parks), medium score parks 23% (5 parks), and low score parks 36% (8 parks). The evaluation results indicate a polarized trend. A targeted optimization of blue-green spaces can be achieved by examining the individual evaluation indicators. Specifically, Yanxi Lake Wetland Park scored the highest at 3264.12, followed by East Lake Scenic Area at 3149.28, and Tangxun Lake Wetland Park at 227.98. These scores are closely related to the high weight given to water retention capacity and the robust retention functions of these parks.

3.1.2 Categorized Service Function Scores

Given the distinct functional orientations of ecological and recreational blue-green spaces in Wuhan, the service function scores were evaluated separately. To minimize the influence of the non-targeted category, its weight was reduced by 90%, and multi-source big data was applied to the service function score calculation model. This resulted in scores for nine ecological spaces (Table 4) and thirteen recreational spaces (Table 5).

Table 4. Synthesis scores of ecological blue-green spaces in Wuhan. Source: Data Processing Results, 2024

Rank	Original Relative Rank	Ecological Blue-Green Space	Synthesis Score
1	1	Yanxi Lake Wetland Park	3566.302

2	2	East Lake Scenic Area	3451.465
3	3	Tangxun Lake Wetland Park	530.154
4	4	Ink Lake Park	364.155
5	5	Huangjiahu Wetland Park	298.468
6	6	Yangchunhu Ecological Park	293.960
7	7	Moon Lake Park	280.403
8	8	Zhangbihu Park	277.721
9	9	Zhuyanghai Park	259.017

Table 5. Synthesis scores of recreational blue-green spaces in Wuhan. Source: Data Processing Results, 2024

Rank	Original Relative Rank	Recreational Blue-Green Space	Synthesis Score
1	1	Fruit Lake Children's Park	202.811
2	3	Shahu Park	43.144
3	2	Small South Lake Park	38.478
4	5	Lingjiao Lake Park	35.267
5	7	Northwest Lake Green Square	14.662
6	11	Fountain Park	5.663
7	8	Baodao Park	4.329
8	6	Ziyang Park	1.232
9	4	Neishahu Park	-0.005
10	10	Simeitang Park	-4.982
11	13	Menghu Park	-14.809
12	9	Houxiang River Park	-22.076
13	12	Lianhua Lake Park	-27.398

The variation in scores of ecological parks is somewhat reduced compared to the overall scores, but the rankings remain the same. This may be due to the higher weight given to ecological attributes in the combined weighting scheme, which has a greater impact on ranking results than recreational attributes. It is important to analyze which indicators scored below average for the lower ranked parks and focus on improving their ecological attributes.

In contrast, the ranking of recreational spaces differs from the overall ranking. For instance, Fountain Park, which was at the bottom of the overall ranking, moved to a middle position after reducing the influence of ecological data. Meanwhile, Houxiang River Park, originally ranked in the lower-middle range, dropped to the second-lowest position without the support of ecological data. Recreational parks that experienced a relatively significant decline in ranking, such as Ziyang Park (down two positions), Neisha Lake Park (down five positions), and Houxiang River Park (down three positions), should prioritize targeted improvements in recreational attributes. Conversely, recreational parks that saw notable increases in ranking, such as Northwest Lake Green Square (up two positions), Fountain Park (up five positions), and Menghu Park (up two positions), need to enhance their ecological attributes, with greater attention required for parks exhibiting larger changes in ranking.

3.2. Evaluation System for Blue-Green Space Service Functions

The comprehensive score for blue-green spaces was calculated by aggregating the specific numerical values analyzed earlier, considering their respective weights. The original values of the calculated indicators were simplified and categorized. Using this scoring system, service function scores for urban blue-green spaces were computed, and grades were assigned to each result through a tiered approach (Table 6). This system, applying a standardized scoring method to various service function levels, facilitates the identification of multidimensional improvement directions for individual blue-green spaces and enables horizontal comparisons and evaluations of urban renewal projects.

Table 6. Scoring system for urban blue-green space service functions. Source: Data Processing Results, 2024

Criterion Level	Indicator Level	Calculated Indicator	Synthesis Score	Segmented Score
Landscape Connectivity	Patch Shape Index	Patch shape index of the landscape pattern	≤112	2
			112-187	4
			>187	6
	Patch Diversion Index	Patch diversion index of the landscape pattern ($/10^4$)	≤68	3
			68-113	6
			>113	9
Stormwater Retention	Water Regulation Capacity	Ratio of retention capacity to retention demand	≤4.3	5
			4.3-7.2	10
			>7.2	15
	Greenness Regulation Capacity	Green space retention capacity ($\times 10^4$ m^3)	≤103	5
			103-172	10
			>172	15
Plant Diversity	Plant Richness Index	Richness of trees, shrubs, and herbaceous plants	≤0.78	2
			0.78-0.87	4
			>0.87	6
	Plant Diversity Index	Diversity of trees, shrubs, and herbaceous plants	≤1.13	3
			1.13-1.41	6
			>1.41	9
Service Area	Walking Service Area	Road network integration within a 2000-meter radius	≤12	1
			12-80	2
			>80	3
	Driving Service Area	Road network integration within a 5000-meter radius	≤150	1
			150-350	2
			>350	3
Spatial Layout	Facility Density	POI density within the space (units/ha)	≤0.21	3
			0.21-0.34	6
			>0.34	9
	Water Proportion	Ratio of water body to total park area (%)	≤39	2
			39-64	4
			>64	6
Service Quality	Park Visitation	Number of park visitors on review websites	≤86	4
			86-143	8
			>143	12
	Visitor Satisfaction	Star rating of park visitors on review websites	≤4.3	2
			4.3-4.5	4
			>4.5	6

3.3. Service Functions of Typical Blue-Green Spaces in Wuhan

The study selected Zhuyanghai Park, which had the lowest overall score, as the evaluation target. Zhuyanghai Park is located between the Qiaokou District and Dongxihu District, bordered by Zhanggong Dike to the north and Yuanbo Avenue to the south. The scores of Zhuyanghai Park are shown in Table 7.

Table 7. Service scores of Zhuyanghai Park. Source: Data Processing Results, 2024

Indicator	Synthesis Score	Z-Score	Segmented Score
Patch Shape Index	131.68	-3.92	4
Patch Diversion Index (/10^4)	177.05	-0.65	9
Water Retention Capacity	32.03	-4.41	15
Greenness Retention Capacity (×10^4 m^3)	31.68	-7.77	10
Plant Richness Index	0.78	0.19	2
Plant Diversity Index	1.1	-10.93	3
Walking Service Area	-15.48	-5.92	1
Driving Service Area	-18.67	-2.94	1
Facility Density (units/ha)	0.27	-3.93	6
Water Proportion (%)	52.22	0.14	4
Park Visitation	17	-10.05	4
Visitor Satisfaction	4.6	6.99	6
Total Score	/	-43.20	65

Among the 12 indicators for Zhuyanghai Park, 3 had positive values and 9 had negative values, with 75% scoring below average. The three lowest scores were for the plant diversity index (-10.93), park visitation (-10.05), and green space water retention capacity (-7.77). Improvements should focus on enhancing plant diversity, increasing park visitation, and boosting the water retention capacity of green spaces. This can be achieved through optimizing park layouts, strengthening green space development, enriching recreational areas, and enhancing plant diversity to facilitate improvements.

3.3.1. Comparison of Service Functions in Typical Blue-Green Spaces

The Zhuyanghai Park (under construction) was compared with the Ziyang Park (fully constructed) in terms of Z-Scores (Figure 3) and segmented scores (Figure 4), with blue bars representing Zhuyanghai Park and red bars representing Ziyang Park.

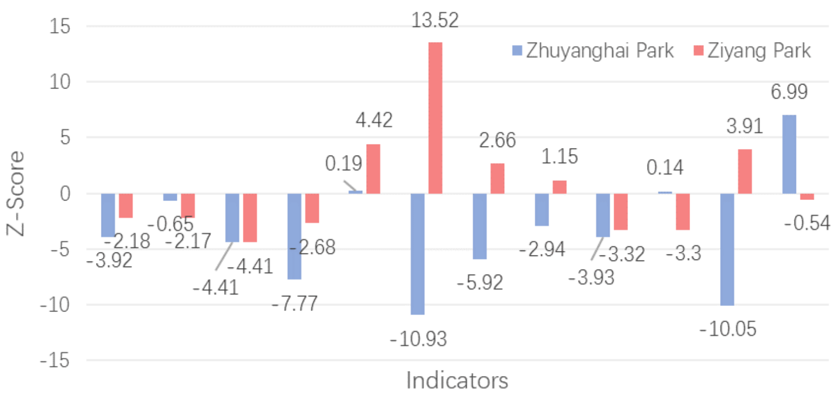

Figure 3. Comparison of z-scores between Zhuyanghai Park and Ziyang Park. Source: Author Analysis, 2024

As shown in Figure 3, the most significant differences between Zhuyanghai Park and Ziyang Park were in plant diversity, park visitation, and walking service area. This contrasts with the individual analysis of Zhuyanghai Park, which indicated that walkability was the main distinction. These differences may be due to the parks' locations and surrounding environments. Ziyang Park is located in Wuchang District, surrounded by well-established residential areas, whereas Zhuyanghai Park is located in Qiaokou District, where most residential buildings are newly constructed or still under construction. Thus, when updating the park, special attention should be given to the unique characteristics of the location and surrounding environment to enhance the area's vibrancy.

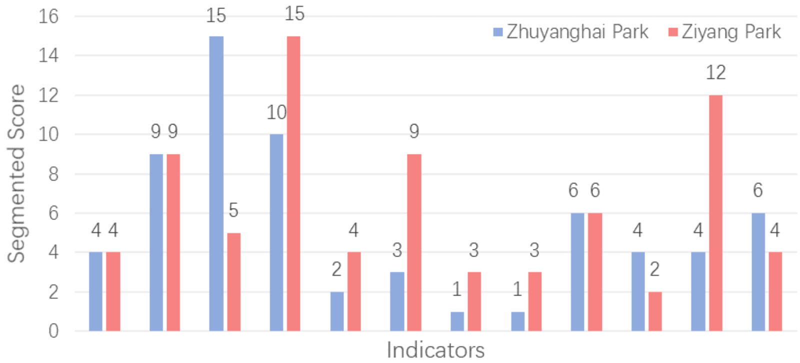

Figure 4. Comparison of segmented scores between Zhuyanghai Park and Ziyang Park. Source: Author Analysis, 2024

As shown in Figure 4, the largest differences between Zhuyanghai Park and Ziyang Park were in greenness retention capacity, park visitation, and plant diversity, which contrast with the rankings based on calculation values. Since greenness retention capacity holds significant weight in the landscape evaluation system, it plays a crucial role in determining scores. Therefore, the park's water retention capacity should be prioritized by implementing low-impact development techniques in coordination with sponge city construction to expand ecological service coverage.

3.3.2. Recommendations for the Renewal of Typical Blue-Green Spaces

Based on the comprehensive analysis of park service scores and comparative assessments, Zhuyehai Park requires enhancements in four key areas: park visitation, plant diversity, greenness retention capacity, and walking service area. Field surveys indicate that the park suffers from low visitation despite good overall ecological conditions. The park lacks basic facilities such as signage systems, resting benches, and lighting. Although the trails and boardwalks are designed for water access, some areas do not adequately considered normal water level, resulting in flooding. In summary, Zhuyehai Park is proposed to function as a bamboo culture theme park, leveraging lake ecological restoration to emphasize ecological green spaces while meeting citizens' needs for leisure, recreation, sports, and culture.

To enhance recreational accessibility, the Third Circulation Line and the Changfeng Avenue overpasses has fragmented the connection between the park and its surroundings. Thus, it is recommended to increase connectivity through pedestrian bridges and underground passages. In addition, the establishment of a primary landscape corridor will create a cohesive spatial network. From an ecological improvement perspective, the site serves as an urban green lung, and better design can enhance its role in ecological restoration. This includes constructing wetland substrates, connecting surrounding green spaces and water bodies, enhancing plant diversity, and creating microclimates to mitigate the urban heat island effect, all guided by ecological principles (Figure 5).

Figure 5. Aerial view, site plan, location map, and on-site photographs of Zhuyehai Park. Source: Wuhan Urban Construction Group, 2022

4. Conclusion

This study developed a service evaluation system for blue-green spaces in central Wuhan. Based on multi-source data, we conducted a comprehensive assessment of recreational and ecological service functions, using Zhuyehai Park as a case study to propose relevant strategies. By investigating the quantitative impact mechanisms of lake parks, we established an evaluation framework that incorporates combined weighting and score calculation. The simplification of service scoring based on data contributes additional evaluation methods and tools, facilitating practical assessment and guidance for the renovation of blue-green spaces. Future research should focus on further improving urban blue-green space services, thereby providing a foundation for enriching the research paradigm of multi-objective planning for urban environment.

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Declaration of generative AI and AI-assisted technologies in the writing process

During the preparation of this work the authors used ChatGPT in order to improve language. After using this tool, the authors reviewed and edited the content as needed and take full responsibility for the content of the publication.

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