ANALYSIS OF ACCESSIBILITY AND LANDSCAPE PATTERNS OF PARKS AND GREEN SPACES IN HEFEI, CHINA

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Abstract. City parks and green space are vital in coordinating urban space and improving the urban ecological environment. Park and green space accessibility is an essential indication of urban livability. Recently, Hefei has become the city with the fastest GDP growth rate in China, little is known about the accessibility and landscape patterns of parks and green spaces in Hefei. We used GIS network analysis and landscape pattern indices to explore the parks and green spaces in the main urban area of Hefei. The results showed that the accessibility to parks and green spaces in the main urban area of Hefei is poor in walking mode, with less than 50% of people able to reach parks and green spaces within 15 minutes. Contrastingly, the accessibility to parks and green spaces in the main urban area of Hefei is good in cycling mode, with 98.06% of people able to reach parks and green spaces within 15 minutes. Furthermore, the parks and green spaces in Hefei have low dimensional indices, indicating high human intervention and regular landscape shapes, which are not conducive to maintaining urban biodiversity and creating natural green landscapes. The spread indices and fragmentation indices of each administrative district are high, indicating a uniform distribution of parks and green spaces. Our study analyzes the accessibility and landscape patterns of parks and green spaces in Hefei, and it will provide a scientific reference for park and green space planning in Hefei.
Keywords: *Hefei, GIS, park green space, accessibility, landscape pattern*

Introduction

Urban parks and green spaces are essential components of urban ecosystems, helping to improve ecological conditions, regulate microclimates, mitigate urban heat island effects, and maintain biodiversity (Coombes et al., 2010; Su et al., 2010; Hsu et al., 2022). At the same time, it is also an important indicator of citizens' quality of life and an important aspect of measuring the level of modern urban development. As the quality of life improves, the demand for urban parks and green spaces is also increasing. People are not only concerned about the quantity and quality of urban parks and green spaces, but also about whether the natural services provided by parks can be accessed conveniently, equitably, and fairly (Santos et al., 2016; Yigitcanlar et al., 2020; Zhang et al., 2022).

Accessibility, also known as reachability, refers to the degree of difficulty or ease with which individuals can reach their intended destination from any point in space. It is a quantitative expression of people's desire and ability to overcome barriers such as distance, time, and cost to access service facilities or activity locations (Pirie, 1979; Reyes et al., 2014;

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Hughey et al., 2016). Currently, the main methods for studying accessibility include buffer analysis (Nicholls, 2001; Miao and Zhang, 2014), gravitational potential model (Talen and Anselin, 1998), cost-weighted distance method (Yu et al., 1999; Dai et al., 2020), network analysis (Nicholls, 2001; Nicholls and Shafer, 2001; Oh and Jeong, 2007), and two-step mobile search method (Li et al., 2019; Tong et al., 2021). These methods reflect the spatial accessibility of service facilities from different perspectives. However, each method has its advantages and disadvantages. For example, the buffer zone method and minimum nearest distance method overlook the resistance during the process of reaching the destination, which can overestimate the accessibility of service facilities (Liu et al., 2010). The gravity model method and cost distance weighting method do not consider the actual path to the destination and generally assign relative resistance to different land use types. However, the classification of land use types and the assignment of relative resistance can be subjective (Tang et al., 2017). The cost distance weighting method requires the subdivision of the study area into large number of networks, and the size of the grid directly affects the accuracy of the calculation (Chen et al., 2015). The network analysis method involves the digital modeling of geographic networks and urban infrastructure networks to study the state of the network and simulate and analyze the flow and allocation of resources on it. It is a spatial analysis method used to study optimization problems related to network structure and resources. During the computation process, it can realistically evaluate the accessibility of service facilities, effectively align travel paths with actual roads, and demonstrate the process of residents entering the park. It can objectively assess the impact of road networks on park accessibility and has become one of the most commonly used algorithms in the evaluation of park and green space accessibility (Nicholls, 2001; Nicholls and Shafer, 2001; Wang and Zhang, 2005; Oh and Jeong, 2007).

The term "landscape pattern" refers to the spatial arrangement and distribution of landscape units, including the number and types of units and their configuration. It is one of the core issues in landscape ecology (Wei et al., 2018; Zhang et al., 2021). The composition and pattern of urban green space landscapes directly impact the sustainable development of cities and the quality of life for residents. With the continuous emergence of urban ecological environmental problems, the study of urban green space landscape patterns has become a hot topic in landscape ecology research. Different cities have significant differences in green space characteristics. It is of great significance to establish a reasonable evaluation index system and evaluation method for the comprehensive evaluation of urban green space landscapes. Hefei, the capital of Anhui Province, has grown fast in recent years, with its GDP climbing from the top 100 in China to the top 20 now. It has become a metropolis of China with the fastest GDP growth rate. However, with the rapid development of the city, whether the construction of urban green parks is reasonable has become a significant aspect affecting urban residents' quality of life. Currently, little is known about the accessibility and landscape patterns of Hefei's parks and green spaces. Therefore, we used GIS network analysis and landscape pattern indexes to explore the accessibility and landscape pattern of urban green spaces in Hefei, and our objective was to provide a theoretical foundation for future optimization of the layout of green parks in Hefei.

Materials and methods

Study site

Hefei is located in the Jianghuai Hills, in the central part of Anhui Province. It has a subtropical, humid monsoon climate, characterized by mild temperatures and distinct seasons.

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In 2021, Hefei developed a city ecological spatial layout of "one lake, one ridge, one core, four zones, and multiple corridors", significantly increasing the area of urban parks and green spaces (Wang et al., 2022; Liu et al., 2023). The scope of this study is the urban monitoring area of Hefei in 2022 (*Figure 1*), which mainly includes the Yaohai area (16569 hm^2), Luyang area (6449 hm^2), Shushan area (24636 hm^2), and Baohe area (17181 hm^2). The total area is 64837 hm^2, with a population of approximately 5.63 million people. Among them, Yaohai District has a population density of 94 people/hm^2, Baohe District has 86 people/hm^2, Shushan District has 76 people/hm^2, and Luyang District has 110 people/hm^2. This region has a high population density and a well-developed transportation system, making it suitable for analyzing the results.

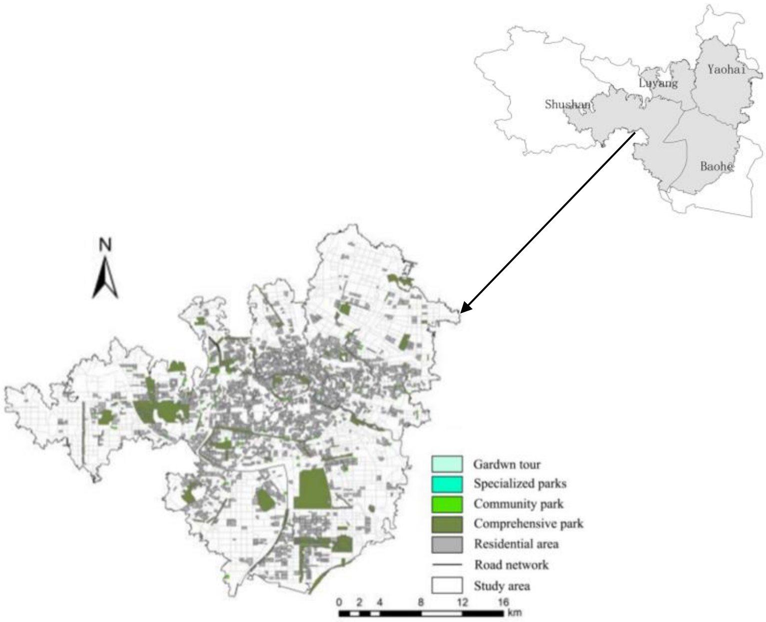

Figure 1. *The area of the study*

Data sources

Quantity and spatial distribution of park green spaces

We only considered the park green spaces that have been completed in the research area. Considering the functions of recreation and leisure provided by park green spaces, those with an area below 0.2 hm^2 are not taken into account (Bussey and Coles, 1995; Chen and Li, 2021). According to the 2017 Urban Green Space Classification Standard (CJJT/85—2017), the park green spaces in the research area are divided into four categories: comprehensive parks, community parks, specialized parks, and amusement parks (*Figure 1, Table 1*). By using high-resolution images and conducting field surveys, the entrances and exits of each park's green space are determined, allowing for more accurate accessibility calculations.

Road network data

The road network data is obtained from the 2022 urban inspection results of Hefei (*Figure 1*). The data does not include Hefei's rail transit data. It focuses on the interruption processing and topological checking of road intersections and other connection points.

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Table 1. *Park green space area in each administrative district of the study area*

Administrative district	Comprehensive park /hm^2	Community park /hm^2	Specialized parks /hm^2	Garden tour /hm^2	The total area /hm^2
Yaohai	525.2	182.4	97.1	23.7	828.4
Shushan	1986.5	260.9	221.9	20.5	2489.3
Luyang	421.3	68.7	25.5	14.1	529.6
Baohe	2019.1	153.6	33.7	23.7	2320.1
Proportion/%	81.5	10.9	6.2	1.3	100

Population data

Based on the results of the 7th National Population Census of China in 2020, we used a Python web scraping tool to crawl the total number of houses in residential communities on Anjuke (https://hf.anjuke.com) and Lianjia (https://hf.lianjia.com) websites, multiplied by the average population per household, to obtain the total population of each community.

Remote sensing image data

We chose Landsat 8 remote sensing photos of Hefei's metropolitan center in 2022 as our primary data source for extracting and evaluating information. Given the large variances in the number of patches and their size distribution in the research area, this study used spatial resolution photos with 15-meter precision to assure visual interpretation clarity and correctness.

Method

Network analysis

Network analysis is a modeling approach used to study geographical networks and urban infrastructure networks. It is primarily used for optimal resource allocation and finding the shortest paths. A basic network consists of centers, chains, nodes, and resistances (Oh and Jeong, 2007; Li et al., 2008; Li and Liu, 2009). In this study, the entrances and exits of the park are considered centers, which reflects the process of citizens entering the park more realistically. For open park spaces, if both sides of the boundary AB allow entrance but any point between AB requires passing through either A or B to enter the park, then all accessible points between AB are represented by A and B. Links represent the actual city transportation network, nodes represent the intersections of roads, and impedance refers to the time it takes for residents to travel through the road network (*Figure 2*).

Accessibility analysis metrics

In this study, we simulate the service area of a city park with a radius of 15 minutes, divided into three time periods: 0-5 minutes, 5-10 minutes, and 10-15 minutes. The modes of transportation are walking and cycling, with a walking speed of 1 m/s and a cycling speed of 4 m/s (Fu, 2021).

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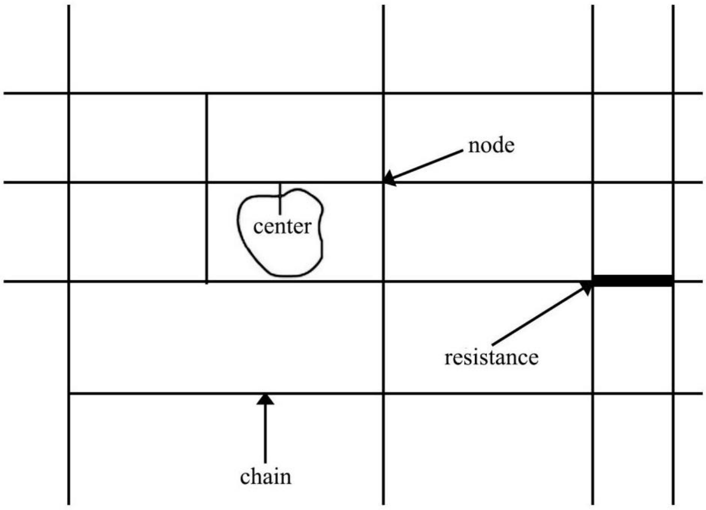

Figure 2. *Basic element diagram of the network model*

This study focuses on analyzing the accessibility of parks and green spaces in Hefei using two indicators: the service area ratio and the service population ratio. The study examines the park service conditions at different travel times, different administrative districts, and different modes of transportation. The specific formulas are as follows:

$$\text{Service area ratio of the study area} = \text{accessible area} / \text{total area} \times 100 \quad \text{(Eq.1)}$$

$$\text{Service population ratio of the study area} = \text{accessible population} / \text{total population} \times 100 \quad \text{(Eq.2)}$$

$$\text{The service area ratio of the administrative district} = \text{accessible area in the administrative district} / \text{total area of the administrative district} \times 100 \quad \text{(Eq.3)}$$

$$\text{Service population ratio of the administrative district} = \text{accessible population in the administrative district} / \text{total population of the administrative district} \times 100 \quad \text{(Eq.4)}$$

City green space landscape pattern indicators

This study aims to convert the vector data of land use types in each administrative region within the study area into raster data. FRAGSTATS4.2 will be used to calculate landscape pattern indices. Five indices, namely diversity index, uniformity index, contagion index, dimensionality index and patch richness density, will be selected to analyze the landscape pattern of urban parks and green spaces in Hefei. The specific methods are as follows (Wagner and Fortin, 2005; Liu et al., 2019):

Diversity index (k_{SHDI}):

At the landscape level, the index is equal to the negative value of the sum of the natural logarithm of the area ratio for each patch type multiplied by its value. This index reflects the sensitivity of landscape heterogeneity to the non-uniform distribution of patch types,

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particularly emphasizing the contribution of rare patch types to the information. The formula is as follows:

$$k_{SHDI}=-\sum_{i=1}^{m} p_i \ln p_i \quad \text{(Eq.5)}$$

Uniformity index (k_{SHEI}):

The concept being described is the degree of evenness in the allocation of different landscape types within a landscape. It is primarily used to measure whether different levels of patches are proportionately distributed in a study area. The formula for this is as follows:

$$k_{SHEI}=\frac{-\sum_{i=1}^{m} p_i \ln p_i}{\ln m} \quad \text{(Eq.6)}$$

Contagion index (k_{CONTGA}):

It is a metric that measures whether a landscape is characterized by the clustering distribution of multiple factors. The formula is as follows:

$$k_{CONTAG}=[1+\frac{\sum_{i=1}^{m}\sum_{k=1}^{m}*[(p_i)(\frac{g_{ik}}{\sum_{k=1}^{m} g_{ik}})]*[\ln((\frac{g_{ik}}{\sum_{k-1}^{m} g_{ik}})]}{2\ln(m)}](100) \quad \text{(Eq.7)}$$

Dimensionality index (k_{PAFRAC}):

It is to measure the stability and complexity of landscape types. The formula is as follows:

$$k_{PAFRAC}=\frac{2[(N\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^2-(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^2]}{[N\sum_{i=1}^{m}\sum_{j=1}^{n}(\ln p_{ij}^2*\ln a_{ij})]-[(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln p_{ij}^2(\sum_{i=1}^{m}\sum_{j=1}^{n}\ln a_{ij}^2)]} \quad \text{(Eq.8)}$$

Patch richness density (k_{PRD}):

It refers to the number of different patch types within the boundary of a landscape divided by the total landscape area. The formula is as follows:

$$k_{PRD}=\mathrm{m/a} \quad \text{(Eq.9)}$$

All data analyses and graphing were carried out with the software ArcGIS version 10.2.

Results

Comparison of walkability and bikeability of parks and green spaces in Hefei

The accessibility of parks and green spaces in the western and northern parts of the study area is low (*Figure 3*). The bikeability of parks and green spaces is significantly higher than the walkability.

Under the walking mode, within 10-15 minutes on foot, the maximum reachable area is 19.20% of the study area, and the population served accounts for 23.64% of the study area population. Within 15 minutes, the reachable area on foot accounts for less than 40% of the study area, and the population served is less than 50% (*Table 2*). The proportion of the reachable population within 15 minutes is higher than the proportion of the reachable

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area, indicating a match between the distribution of parks and the distribution of population. Under the cycling mode, the best accessibility is within 0-5 minutes, with a reachable area proportion of 46.92% and a reachable population proportion of 61.59%. Within 15 minutes, the reachable area proportion reaches 81%, and the reachable population proportion reaches 98% (*Table 2*).

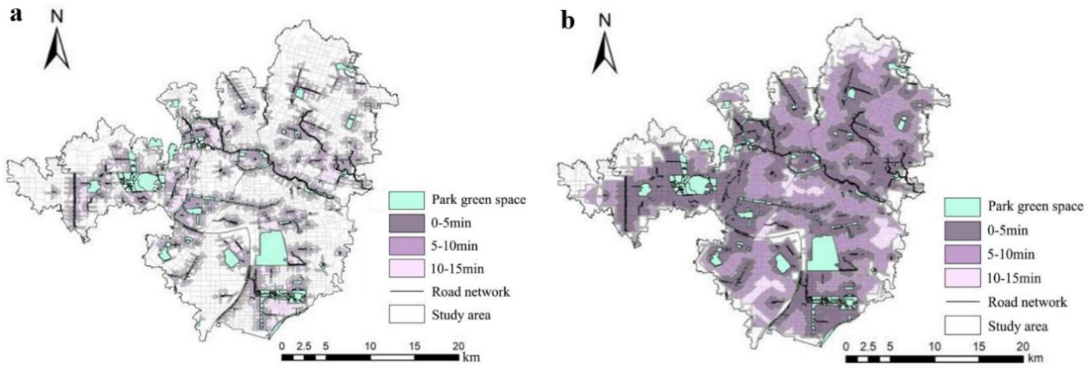

Figure 3. *Distribution of accessibility levels of park green spaces in Hefei under walking mode (a) and cycling mode (b). Darker colors represent better accessibility, while lighter colors indicate worse accessibility*

Comparison of accessibility to parks and green spaces in different administrative districts in Hefei

In walking mode, the accessibility of Luyang District within 15 minutes is the best. The accessible area accounts for 47.15% of the study area, and the accessible population accounts for 56.66% of the study area's population. In comparison, the accessibility of Baohe District within 15 minutes is the poorest, with the accessible area accounting for 40.20% of the study area and the accessible population accounting for 36.38% of the study area's population (*Figure 4a, b*). In cycling mode, the best accessibility to parks and green spaces within 15 minutes is in Baohe District, with an accessible area ratio of 86.71% and an accessible population ratio of 99.72% (*Figure 4c, d*). Baohe District has a well-planned overall layout, a relatively complete road network, and a higher number of large parks. Therefore, in cycling mode, the accessibility is better in Baohe District compared to the other three districts.

Analysis of landscape patterns

Using Fragstats 4.2, the landscape pattern indices for the overall study area and each administrative region were calculated (*Table 3*). The results indicate that the overall study area has relatively low dimensionality (below 1.25). The landscape contagion index in Baohe District is the lowest at 69.72, and the evenness index is the highest at 0.57, suggesting that the distribution of parks and green spaces in Baohe District is relatively uniform but with a high degree of fragmentation. On the other hand, Yaohai District has lower fragmentation and a more uneven distribution. Luyang District has the highest patch richness density, while Shushan District has the lowest patch richness density.

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Table 2. *Statistics of various indicators of Hefei's park green spaces under walking and cycling modes*

Travel mode	Accessibility /min	Area /hectare	Cumulative area	Area ratio/%	Cumulative area ratio/%	Number of community	Population	Cumulative population	Population ratio/%	Cumulative population ratio/%
Walk	0-5	4516.2	4516.2	6.97	6.97	128	321831	321831	5.72	5.72
	5-10	7998.9	12515.1	12.34	19.30	387	939138	1260969	16.68	22.40
	10-15	12447.7	24962.8	19.20	38.50	583	1330878	2591847	23.64	46.04
Cycling	0-5	30422.2	30422.2	46.92	46.92	1370	3467729	3467729	61.59	61.59
	5-10	16892.3	47314.5	26.05	72.97	757	1796248	5263977	31.90	93.50
	10-15	5205.24	52519.74	8.03	81.00	130	256651	5520628	4.56	98.06

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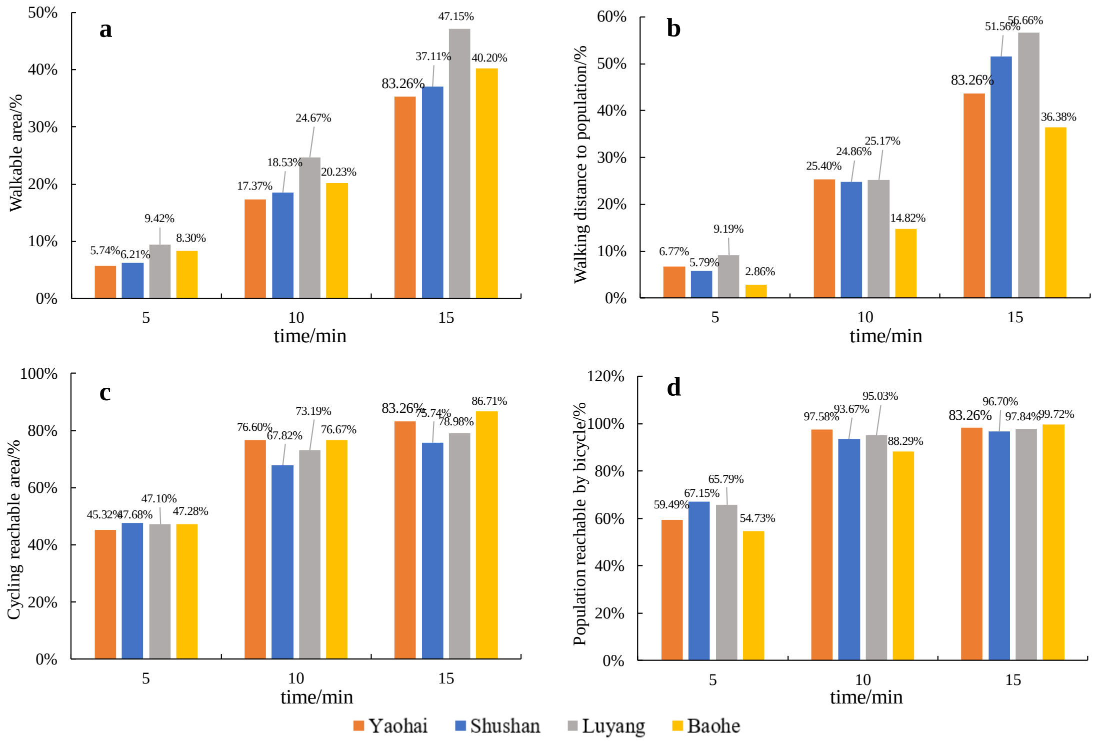

Figure 4. *Accessibility of park green space in the administrative district under walking mode (a, b) and cycling mode (c, d)*

Table 3. *Park green space landscape pattern index in the study area*

Site	PAFRAC	CONTAG	PRD	SHDI	SHEI
Yaohai	1.2261	84.641	0.0116	0.1933	0.2789
Shushan	1.1576	74.7966	0.0081	0.3274	0.4723
Luyang	1.2059	77.2749	0.031	0.2844	0.4103
Baohe	1.1464	69.7284	0.0121	0.3951	0.5701
Study area	1.1451	75.2876	0.006	0.8582	0.479

Discussion and Conclusions

In this study, we used network analysis to assess the accessibility of park green spaces in the research area. We also evaluated the quality of park green spaces in different areas based on landscape pattern indices. The following conclusions were drawn:

(1) In general, the accessibility of park green spaces in the research area is much higher for cycling mode compared to walking mode. Within 15 minutes, the park green spaces accessible by walking accounted for 38.5% of the research area and 46.04% of the population.

(2) From the perspective of the study area, the pedestrian accessibility to parks and green spaces in Luyang District is the highest, with an accessible area accounting for 47.15% of the administrative area and an accessible population accounting for 56.66%. In the cycling mode, the accessibility to parks and green spaces in Baohe District is the best, with an accessible area accounting for 86.71% of the study area and an accessible population accounting for 99.72%. This is because Luyang District has a smaller area and

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higher population density, with park distribution matching population distribution, which can meet the needs of more residents who primarily use walking. Baohe District has better overall planning, a more complete road network, and more large parks, so the accessibility is better than the other three districts in the cycling mode.

(3) The distribution of green spaces in the study area is relatively even and matches the population distribution. The overall dimensionality of green spaces in the study area is low, indicating a high degree of human interference and a more regular landscape shape, which is not conducive to maintaining urban biodiversity and creating natural green landscapes. The sprawl index of green spaces in each administrative district is relatively high, indicating a high level of fragmentation in urban parks. Among them, Baohe District has the best uniformity of green space distribution, while Yaohai District has the worst.

There are several areas for improvement in the research. The network analysis method is typically based on comprehensive data such as park classifications, roads, and population. The availability and quality of these data directly determine the accuracy and scope of the research findings, requiring collaboration and support from relevant government departments and research institutions. In the calculation of accessibility based on road networks, factors such as road conditions and gradients are not considered, and using average travel speed for calculation can affect the accuracy of accessibility results. Additionally, the exclusion of small green spaces in parks that are less than 0.2 hectares may result in lower accessibility. There are multiple factors that influence accessibility indicators, and further research is needed to consider different urban land uses, transportation characteristics, and factors such as vertical elevation and connectivity, as well as to quantify these factors and their relationship with spatial accessibility.

There are also some shortcomings to be discussed in this article. In addition to factors such as transportation networks, travel modes, and population density, the primary audience of the park, and the history and culture of the park are factors that may influence accessibility results. Therefore, these factors also need to be considered in future park green space accessibility analyses. Furthermore, this study did not consider subway lines in the road network system. Especially, the speed of subway lines, stopping time, economic costs, and the willingness of residents to travel to park green spaces by subway are all factors that influence accessibility. In the future, it is necessary to consider incorporating the subway into the road network system to further analyze its impact on the accessibility of urban green spaces.

Author Contributions. ZS initialized the project. ZS and PY collected and analyzed data. ZS wrote the first draft, with substantial input from PY, YT, YZ, YQ and YH. All authors contributed critically to the draft and gave final approval for publication.

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