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Study on the Spatial Arrangement of Urban Parkland under the Perspective of Equity—Taking Harbin Main City as an Example

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Abstract: The connotation and measurement standard of "fairness" in parkland planning is closely related to the level of urban development and residents' needs, with solid realism and dynamics, and it is still a complex problem to control accurately in planning. Therefore, to conduct a more comprehensive study, taking the main urban area of Harbin as an example, this paper combined urban development background and practical problems at different stages and, based on POI and AOI data, divided the connotation of "equity" in park green space planning into two levels: "spatial equity" and "social equity". Based on these two levels of fairness, the research framework of urban park green space layout is constructed. Kernel density estimation and GIS-based network analysis were used to study the spatial layout and accessibility of urban parkland. The ability to match supply and demand for parkland in the study area as a whole was analyzed using a gridded two-step moving search method, as well as the degree of equity in the enjoyment of urban parkland by vulnerable groups including the elderly and children using the Lorenz curve with the Gini coefficient, the share index, and the entropy of the locality. The results show that: (1) the parkland is concentrated in the seven main urban areas of the two–two junctions, and the cohesion distribution trend is outside the distribution. (2) Motorized vehicles have the best 15-min accessibility for travel, but it still does not cover all the parkland. (3) Supply and demand within the region are unsatisfactory, with the area with the strongest supply and demand capacity for parkland accounting for only 3.19% of the total area. (4) The Gini coefficient of parkland enjoyed by the residents of Harbin city center is 0.407, with a massive gap in the overall distribution. In addition, the share index of vulnerable groups of the elderly and children all have share indices below 1, and the results of the analysis of locational entropy indicate that the level of street park green space resources enjoyed by these two groups belongs to the low socio-spatial equity pattern, which is not balanced. This study investigates the spatial layout of urban parkland from two equity levels, which can provide new ideas for the equity study of urban green space planning.

Keywords: parkland; equity; GIS; two-step mobile search method; vulnerable groups

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1. Introduction

As a common good, urban parkland provides a place of leisure, recreation, and relaxation for urban residents and an essential guarantee for urban landscape and ecological balance, which has significant economic effects and ecological benefits in urban planning [1]. China has entered the stage of high-quality development, relying only on the quantity of parkland, size, coverage, and other criteria to appraise urban parkland. It has yet to meet the requirements of the new period of spatial structure optimization based on incremental increase [2]. The 2022 assessment report on China's major urban parks states that the essence of the scarcity of urban parkland is the unequal distribution process of urban parkland [3]. Therefore, it is of great importance to study the matching degree and coordination degree of parkland supply and demand, evaluate the balance of parkland

supply and demand, and evaluate the fairness and social justice of parklands for the research and practice of public policy of urban parkland construction.

Studies on the equity of parkland began in the 1960s when a great deal of injustice and geographic inequity emerged. Moreover, with the rapid growth of cities, inequality continues to grow [4]. In the 1970s, European and American countries established relatively perfect social welfare systems, and some scholars believed that the spatial equity problem of urban parkland use mainly existed in the overall quantitative indicators such as per capita parkland area, thus ignoring the distribution structure and quality of urban parkland and other factors. For example, William Lucy's "Five Sub-concepts" [5] and Bruce E. Wicks et al.'s "Three Criteria" [6] are relatively representative theories in fairness evaluation from that time. They believe that the layout of public service resources should consider the quantity and specific location and, based on meeting the minimum demand level, ensure that people have the same opportunity to use public service resources and that the service efficiency of public service resources can be fully exerted. The progress lies in the minimum demand standard, and the service efficiency of public resources is taken into account, but the essence is still the idea of equal distribution. This evaluation method does not take into account the actual needs of different social groups for the use of green space resources, nor does it analyze the actual location layout or service benefits of urban park green space. Therefore, the fairness discussed by these evaluation indicators has certain limitations.

As time went on, after the 1970s, researchers began to pay attention to the efficiency of parkland, that is, how to achieve a balance between the supply side and the demand side, and introduced the social dimension into the study of the supply and demand balance of parkland, considering the difference in demand of different groups [7]. Sociologists have proposed that factors such as ethnic culture, age distribution, and the neighborhood environment have an impact on the demand for parkland [8,9]. For example, Dajun Dai explored whether urban parkland accessibility is evenly distributed under the influence of race and socioeconomic factors [8]. On the other hand, the needs index is widely used to evaluate the fairness of green space resource allocation [10]. Yin Haiwei et al. proposed that only when population needs are taken into account in the allocation and layout of urban public parkland resources, can it be considered to be spatially fair [11].

In recent years, guided by the idea of environmental justice, domestic studies have also begun to pay attention to the unequal phenomenon of different social attribute groups benefiting from parkland services and have proposed to enhance the equality of the quantity, area, and quality of parkland accessible to different groups [12]. Parkland planning has gradually shifted from the traditional perspective of supply as the main body to the consideration of the demand-side status, and the level of research has also shifted from only satisfying "spatial fairness" to satisfying spatial fairness and considering "social fairness" at the same time [12,13]. For example, Feyzan Erkip believes that the issue of equity requires comprehensive consideration of the actual needs and usage modes of different social groups [14]. Emily Talen emphasized the concept of social justice and believed that the distribution of public service resources should be tilted toward vulnerable groups so that low-income groups can enjoy a higher degree of spatial supply accessibility [15].

In terms of research methods, in the accessibility analysis and research in the spatial equity stage, scholars only consider the spatial layout of urban parkland, while in the social equity stage, different social groups are combined to discuss the accessibility situation differently. Based on actual calculation and analysis, land use, traffic, distance, residential area or population, and individual characteristics are all factors that affect accessibility analysis results [16]. It can be seen that the factors affecting the equity of urban parkland resources can be summarized into two aspects: first, the accessibility characteristics of urban parkland, and second, the spatial differentiation of different user groups. For example, based on a review of conventional parkland planning and layout means, mainly using the comprehensive judgment of artificial experience and the current situation, that is, selecting the location of parks and deciding the grade of parks based on unique sites in a planning area such as mountains, water bodies, and areas with good vegetation coverage,

deciding the arrangement of parkland based on the radius of service [17,18], etc., Wan Song and Fan Zhulian consider the impacts of different modes of travel on accessibility, and research the accessibility of the urban parkland of the main urban area of Zhangzhou City using the method of network analysis [19]. Hu Ang et al. utilized the improved two-step mobile search method, considered the park entrance location, and constructed a system of indicators such as the ratio of the population served by the park and the ratio of the area served by the park for evaluation [20]. Tang Zilai and Gu Shu investigated the distribution of urban parkland in Shanghai, aiming to move toward social equity. They used the Gini coefficient and location entropy method for this purpose [21].

Research Purpose

In summary, as mentioned above, most of the fairness studies of parkland focus on a single factor and rarely consider the combination of destination accessibility, the degree of matching between needs and the fairness of serving vulnerable groups, and the lack of horizontal and vertical comparative studies between parkland at different levels of fairness. Therefore, this study chooses the main urban area of Harbin as the research object and combines various research methods from the two levels of "spatial equity" and "social equity".

At the level of spatial equity, we aim to evaluate whether the spatial distribution of parkland in the urban research area is balanced and explore the accessibility and utilization of parkland by residents in different areas. The goal is to reveal how spatial layout affects or exacerbates inequalities between regions, identify key factors affecting spatial equity, and finally, propose strategies to promote a more balanced distribution of parkland layout.

At the level of social equity, the humanistic concept of "people-oriented" is applied to the planning, construction, and development of public resources [22], aiming to study how the spatial layout of parkland affects the use of residents in different social backgrounds, especially the service coverage for vulnerable groups, and further analyze the social equity of parkland service. This study concludes by exploring planning principles and practices that promote social equity, in particular, how parkland is designed and managed to meet the needs and expectations of all communities and promote social inclusion and cohesion. At the same time, big data are introduced as a tool to quantify the use and needs of the population to better show the degree of residents' sharing of urban park resources. In short, this study aims to help adjust and optimize the layout of parkland planning and provide a basis for realizing the fairness between urban parkland planning and construction and citizens' needs.

2. Materials and Methods

2.1. Overview of the Survey Region

Harbin is the capital of Heilongjiang Province and the center city of the northeastern part of China. It is an essential national manufacturing base, a famous historical and cultural city, and an international ice and snow cultural city. Because some urban areas in Harbin are not well developed and have a low population density, the main urban area, which is well constructed and has a concentrated population density, was selected as the survey region, which is more meaningful for this study. The main urban areas selected for this paper include the planned urban built-up areas of Daoli District, Daowai District, Nangang District, Xiangfang District, Pingfang District, Songbei District, and Hulan District, with a total land area of 4631.7 km^2 (Figure 1). According to the master plan of Harbin City, by 2020, the greening rate of the main urban area was predicted to reach more than 38%, and 2598 m^2 was predicted to increase based on the original public green space of 2094 m^2. At present, the parkland in the main urban area is 3039 m^2, accounting for 64.77% of the public green space in the main urban area.

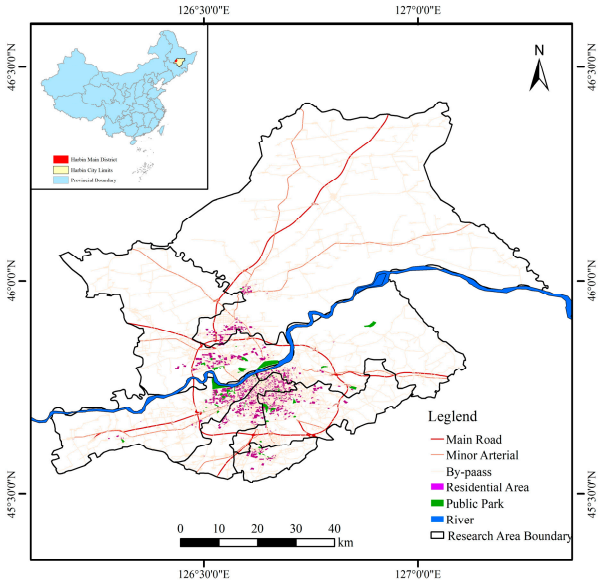


Figure 1. Survey region in the primary urban area of Harbin.

2.2. Data Sources and Pre-Processing

The primary data used in this study include (1) the administrative boundary data (district level) on the main urban area of Harbin City in 2021, which were derived from platforms such as Tianmap and DataV.GeoAtlas, and were mainly used to determine the scope of this study and the study unit; (2) POI and AOI data on residential areas and parkland in the primary urban area of Harbin City, derived from Baidu Open Platform and Gaode Open Platform, which were mainly used to provide park green space supply; and (3) road data on Harbin's main urban area, obtained through Open Street Map (OSM) and using the Open Platform of Gaode Map (AMAP Inside), which were used as verification. (4) The required data for calculating the demand for park green space includes two sources: the 2020 Worldpop 100 m Population Grid (available at https://www.worldpop.org, accessed on 11 November 2023), which provided information about population distribution, and the 7th Population Census data (district level) available on the Harbin Municipal People's Government website, which were used to adjust the population grid (Figure 2).

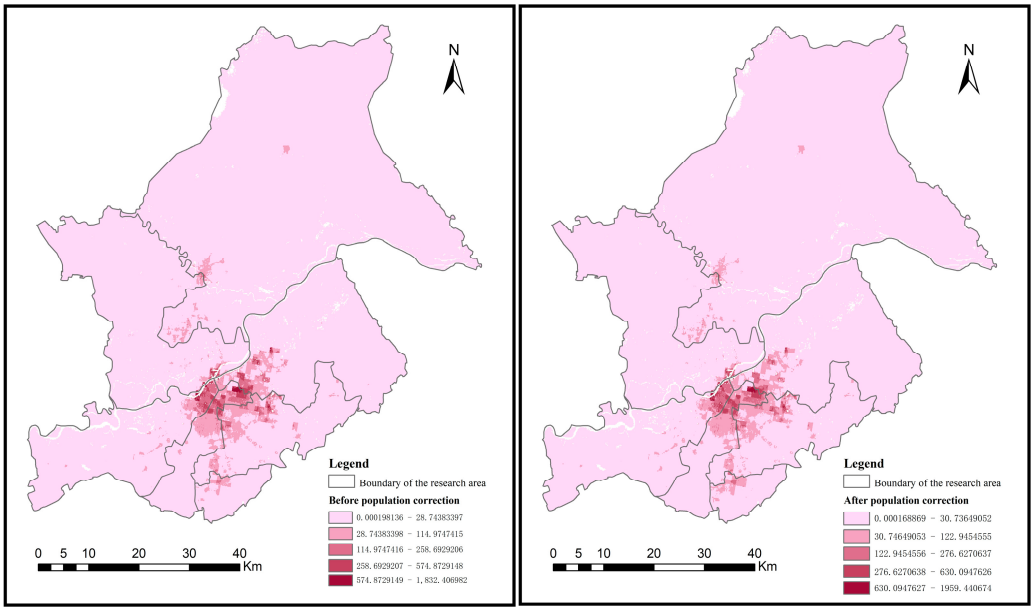


Figure 2. Population correction before and after.

2.3. Research Methodology Framework

As a public good, urban green space has essential economic and ecological benefits in urban planning. However, there are inequities in the allocation process of urban parkland, and disadvantaged groups' voices need more consideration [23,24]. Therefore, the study of spatial justice in urban parkland is of great importance to the research and practice of public policy on urban green space construction. This paper constructs a parkland layout equity research framework for empirical case analysis of parkland in the primary city of Harbin (Figure 3), divided into the two levels of spatial equity and social equity.

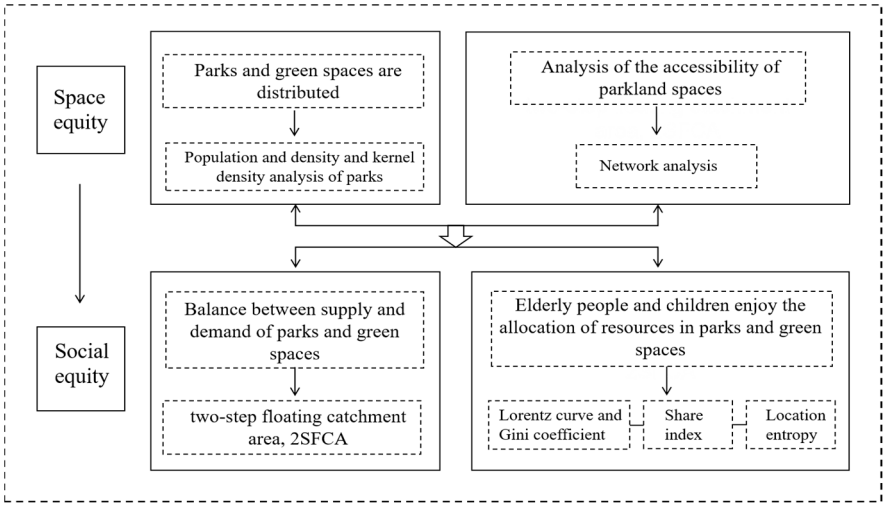


Figure 3. Research flowchart.

At the level of spatial equity, first of all, the emergence of modern urban parks originated from urban problems in early industrialization, in order to solve the problems of urban population growth, inadequate infrastructure, and declining environmental health. At this stage, the development of parkland is regulated by the land development right to ensure that the per capita service amount of parkland in different regional spatial units is basically equal. Therefore, this paper applies the kernel density estimation method to consider the distribution and quantity equality of parkland in the whole study area. Secondly, with the acceleration of urbanization, parkland planning began to emphasize fairness and pay attention to the relationship between parkland layout and population use effect. The development of accessibility theory promoted the expansion of parkland planning from "equal scale" to "spatial balance" to ensure that residents in different locations could obtain effective service opportunities of parkland within the accessible range. Therefore, this paper uses network analysis to study the regional balance under accessibility guarantee.

At the level of social equity, first of all, under the guidance of the concept of environmental justice, parkland planning began to pay attention to the unequal benefit of parkland services among social groups. In improving the demand response of park green space, and in the planning of parkland, both the supply side and the demand side can enjoy equal services and resources. This means that the scale, spatial allocation, and service performance of parkland should be able to meet the needs of different groups and ensure that everyone can equally enjoy the services and welfare provided by parkland, representing a rise from the level of "spatial equity" to "social equity". Therefore, in the context of the environment at this stage, this paper presents the following measure: an improved two-step mobile search method used to analyze the state of "space matching" and "coordinated development" between parkland supply and social demand.

Secondly, as urban development enters the stage of fine governance, parkland planning begins to pay attention to micro-renewal, micro-transformation, and other practices. By implementing urban renewal projects that supplement parkland, transform parkland itself, and improve travel conditions, the number, scale, and quality of parkland accessible to

vulnerable groups can be improved to achieve group equality. These processes reflect the attention and continuous development of fairness in different stages of parkland planning. In summary, there is a gradual transition from the research level of spatial equity to the research level of social equity. The goal of these development processes is to ensure the equitable development of parkland so that all social groups can enjoy the services and benefits of parkland. Therefore, this paper uses the Lorentz curve, the Gini coefficient, the share index, and location entropy to measure the fairness of parkland use in elderly and child groups so as to emphasize the inclination of parkland resources to socially disadvantaged groups.

2.4. Research Methods of Spatial Equity

2.4.1. Kernel Density Estimation

Kernel density estimation (KDE) is a method used to analyze spatial distribution [25]. In the KDE method, each sample point of an element is used as a search center, and the spatial distribution of the element is characterized by calculating the density in the neighborhood around the sample point. Elements closer to the sample point have larger attribute values, and elements farther away have smaller attribute values. The density value of the sample point is obtained by calculating the weighted average density of all elements in the area. The kernel density estimation method is formulated as follows:

$$f_n(X) = \frac{1}{nh} \sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (1)$$

where $f_n(X)$ is the kernel density function at sample point x, h is the sensory threshold radius set by the kernel density function, n is the total quantity of sample points, x_i are the locations of the sample points, k is the weighting function of the distance, and $x - x_i$ is the distance from the elemental point x to x_i. In the KDE method, the choice of the threshold radius h significantly impacts the results. A smaller threshold radius is suitable for analyzing local features, and a larger one is suitable for analyzing overall distributional features. Therefore, this paper applies the kernel density analysis method to study the distribution of parkland in the main city of Harbin and the characteristics of population aggregation and overall spatial distribution characteristics.

2.4.2. Network Analysis Method

Network analysis is based on network structure and path analysis for assessing and analyzing the accessibility and connectivity between spatial objectives. In urban and transportation planning fields, the network analysis method is commonly used to assess the service coverage of public facilities, the efficiency and accessibility of transportation networks, and other issues [26]. Using network analysis to grade the accessibility of parkland and assign values to each level, conclusions can be drawn about the spatial accessibility of parkland for walking traffic, public transportation, and cycling traffic modes [27]. Network analysis is an analytical and computational method that utilizes network topological relationships, spatial and attribute data, and mathematical theoretical models for multifaceted studies. In Geographic Information Systems (GISs), network analysis is a module for calculating shortest paths, service areas, facility points, location relationships, etc., based on geographic networks (e.g., transportation networks) [28]. Network analysis can optimize resource allocation by simulating realistic transportation modes like walking, cycling, and transit. The essential elements of network analysis include centers, connections, nodes, and resistance, which are used to determine the interrelationships and accessibility between spatial goals by constructing road network datasets [28,29].

In this paper, parkland is selected as the center, the road network in the study area as the connection, the intersection of the roads in the study area as the node, and the time cost spent on the road as the resistance. Moreover, the network dataset is constructed based on

vectorized roads, and the vectorized roads are assigned corresponding essential attributes such as road class, road length, and travel time. Then, the connectivity of the network is set, the network properties are specified, and the resistance value is set. Walking, cycling, and motor vehicle travel are the basic travel transportation modes for residents, and this paper considers the following when selecting the speed of each transportation mode: According to the normal human walking speed per minute of about 1 m/s, the step distance of about 60–75 cm, the frequency of one and a half steps per second, and a one-minute walking distance of 60–100 m, the average speed of walking is 4–5 km per hour. Therefore, in this paper, we set the average speed of walking at 5 km/h. According to the "People's Republic of China Road Traffic Safety Law" in Chapter IV of the third section on road traffic regulations: regarding the driving speed limit for disabled motorized wheelchair vehicles and electric bicycles on non-motorized roads, the maximum speed shall not exceed fifteen kilometers per hour. Therefore, in this paper, we set the average riding speed at 15 km/h. Motor vehicles travel according to different levels of roads and set different speeds. According to the "urban, comprehensive traffic system planning standards" (GB/T51328) combined with the actual situation, roads are divided into 3 types: main roads (60 km/h), secondary roads (40 km/h), and side roads (30 km/h), assuming that all roads in the city travel in both directions and have 30 s of waiting time at intersections. Finally, the accessibility of parkland for different travel modes was analyzed. The ratio of accessible area to accessible population in the study area was calculated (Equations (1) and (2)), and the relevant data were summarized.

The formula for calculating the accessibility indicator is as follows:

$$\text{Accessible Area Ratio} = (\text{Accessible Service Area}/\text{Total Study Area}) \times 100\%$$

$$\text{The ratio of the quantity of accessible neighborhoods} = (\text{quantity of accessible service neighborhoods}/\text{total number of neighborhoods in the study area}) \times 100\%$$

2.5. Research Methods for Social Equity

2.5.1. Gridded Gaussian Two-Step Moving Search Method

The two-step mobile search method is a method used to assess the accessibility of urban parkland. The method calculates each demand unit's supply/demand ratio to the surrounding parkland by dividing the city into demand and supply units and considering factors such as time cost and spatial friction [30,31]. This article uses the following specific steps:

First of all, the center of mass is extracted for the park green space as the park green space supply point j. The road network limit distance d_0 (based on TD/T 1062-2021 Technical Guidelines for Community Life Circle Planning issued by the Ministry of Natural Resources, the 15-min Community Life Circle Slow Walking Network selects 1000 m as the road network limit distance d_0 [32]) for people going to the park green space is used as the radius to establish the search domain j, summarize the number of all populations in the search domain j, assign weights using the Gaussian function by the distance decay law, and sum and aggregate these weighted populations to compute the supply–demand ratio R_j [33].

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} G(d_{ij}) D_k} \tag{2}$$

where D_k is the population of each demand unit (in this research, a 200 m × 200 m grid is used to grid the study area, and the center of the grid is selected as the demand point D_k) and d_{kj} is the road net distance between locations k and j. For parks with multiple entrances, the road network distance from the demand unit to the nearest entrance is selected, and the unit k needs to fall within the search domain (i.e., $d_{kj} \le d_0$); S_j is the area of the parkland j;

and $G(d_{ij})$ is a Gaussian attenuation function that considers the spatial friction problem, and its specific form can be expressed as follows:

$$G(d_{ij}) = \frac{e^{-\frac{1}{2}\times\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}} \quad (d_{ij} < d_0) \tag{3}$$

Then, any residential area is selected as the demand point i, and the limit distance d_0 is taken as the radius to search all the parkland j in the domain. Based on the Gaussian attenuation function, the supply and demand ratio R_j of the parkland is summarized and summed to obtain the accessibility ${A_i}^D$ of residential areas i. [33]:

$$A_i^D = \sum_{j\in\{d_i\le d_0\}} G(d_{ij})R_j \tag{4}$$

2.5.2. Lorenz Curve and Gini Coefficient

The Lorenz curve was developed by the American statistician M.O. Lorentz in 1905 or 1907. In recent years, the Lorenz curve has been widely used in urban and rural planning; for example, the Lorenz curve can be used to analyze the income distribution between urban and rural areas. The earliest applications began with Jin Yuan (2006), who used the above two indicators to evaluate the equity level of green space resources [34]. Nowadays, the Lorenz curve and the Gini coefficient are mostly applied to analyze the social equity of parkland in terms of residents' enjoyment (Ma Yue et al., 2021) [35]. In this paper, the parkland enjoyed by the residents within the square of the study area will be divided into X hierarchical groups in the order from low to high. Each hierarchical group accounts for X% of the population to calculate the proportion of the park area enjoyed by the residents of each group to the total area of the parkland within the survey region. Then, we take the cumulative percentage of population as the horizontal axis and the cumulative percentage of parkland as the vertical axis and plot a curve reflecting the disparity in the distribution of parkland among residents, which is the Lorenz curve. (Figure 4).

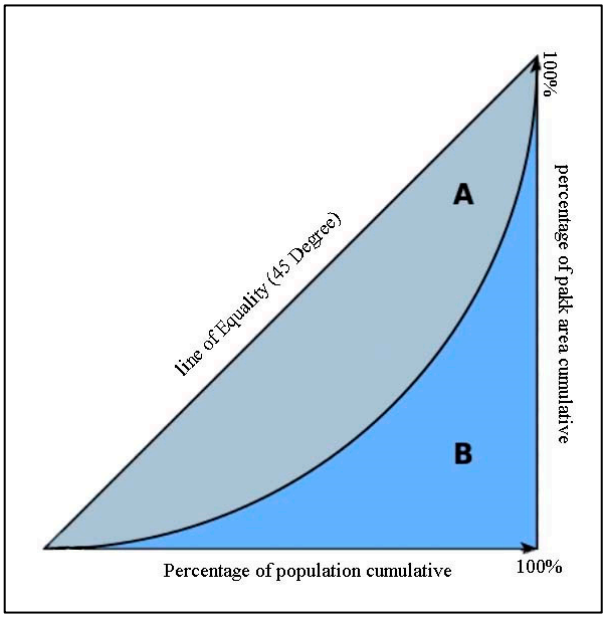


Figure 4. Schematic diagram of the Lorentz curve.

The Gini coefficient was proposed by Italian economist Corrado Gini in 1912, and it is a commonly used indicator to measure the income disparity among residents of a country or region. Many scholars now use it to assess the inclusiveness and equity of cities [36].

The Gini coefficient is expressed as the A/(A + B) ratio in the Lorenz curve diagram. The area between the ratio of the area of parkland enjoyed by the residents in the actual study area (the Lorenz curve) and the straight line of absolute equality of the ratio of the area of parkland enjoyed by the residents in the survey region is A. The area at the bottom right of the curve of the ratio of the area of parkland enjoyed by the residents in the actual study area is B. The range of values is between [0 and 1]; the closer the Gini coefficient is to 1, the more unequal the distribution of park green space within the city and the bigger the gap; the closer the Gini coefficient is to 0, the more equal the arrangement of parkland within the city and the smaller the gap (Table 1).

Table 1. Determination of the Gini coefficient by the United Nations Development Programme and others.

Gini Coefficient Rating	**<0.2**	**0.2–0.29**	**0.3–0.39**	**0.4–0.59**	**>0.6**
Degree of distributional disparity	Highly average	Comparatively average	Relatively reasonable	The gap is wide	Highly disparate

2.5.3. Share Index

The share index is a social justice performance evaluation methodology that measures the proportion of the allocation of public resources that a particular social group accounts for. It assesses social justice by calculating the difference between a particular group's share of public resources and that group's proportion of the overall population. A value of the share index that is greater than 1 indicates that the group has a share in the distribution of resources that exceeds its proportion of the overall population. In contrast, a value of less than 1 indicates that the group has a share in the distribution of resources that is less than its proportion of the overall population [21].

Firstly, the proportion of public green space resources enjoyed by the elderly and child groups to the total public green space resources is measured.

$$R = \sum_{j=1}^{n} P_j X_j 100\% \quad (5)$$

where j denotes the street within the survey region, P_j denotes the ratio of disadvantaged groups to the resident population in area j, and X_j denotes the ratio of parkland in area j to the total green space in the entire survey region.

Then, based on the R value, the share exponent of parkland resources entitled to disadvantaged groups is calculated, and the calculation formula is as follows:

$$F = \frac{R}{P} \quad (6)$$

where R is the share of public parkland resources enjoyed by disadvantaged groups and P is the share of disadvantaged groups in the resident population. A share index F value of greater than 1 indicates that the share of public parkland resources enjoyed by disadvantaged groups is higher than the average share of society, and vice versa for F values of less than 1.

2.5.4. Locational Entropy (Physics)

Location entropy was first proposed by P. Haggett for use in location analysis. At present, location entropy is mainly used to assess the distribution of spatial units, which can measure the degree of difference in the distribution of a particular group in different spatial units. By calculating location entropy, we can judge whether there is a spatial imbalance phenomenon [21,37]. The higher the value of locational entropy, the more unbalanced the spatial distribution of that particular group and the higher the level of per capita enjoyment of park green space resources in that region. In contrast, the opposite is true for lower values. The calculation formula is as follows:

$$LQ_j = \frac{(\frac{T_j}{P_j})}{(\frac{T}{P})} \quad (7)$$

where LQ_j is the locational entropy of each region j, T_j is the total amount of parkland resources in each region j, P_j is the number of elderly disadvantaged groups in each region j, T is the total amount of parkland resources in the survey region, and P is the total population in the study area. A locational entropy > 1 indicates that the parkland resources per capita entitled to the disadvantaged groups in the district are greater than the overall level of the survey region scope, and the reverse is true if the locational entropy < 1.

3. Results

3.1. Analysis of Parkland Layout and Accessibility under the Spatial Equity Hierarchy

3.1.1. Analysis of Parkland Layout Based on the Kernel Density Estimation Method

Based on the Kernel Density Analysis tool in the ArcGIS 10.8 software, KDE was carried out to analyze the population and parkland in the survey region (Figure 5). Based on the nuclear density analysis, it can be seen that the primary urban areas of Harbin, both in terms of population and parkland, are concentrated in the northwest of Hulan District, the southeast of Songbei District, the southwest of Daowai District, the northeast of Daoli District, the northeast of Nangang District, the northwest of Pingfang District, and the western part of Xiangfang District. The overall layout shows the distribution structure of clustering in the center of the main city and scattering in the surrounding undeveloped areas. From the seven main urban connecting areas to the periphery of the gradual decreasing trend, the overall view of the main urban parkland distribution is more in line with the structure of population development.

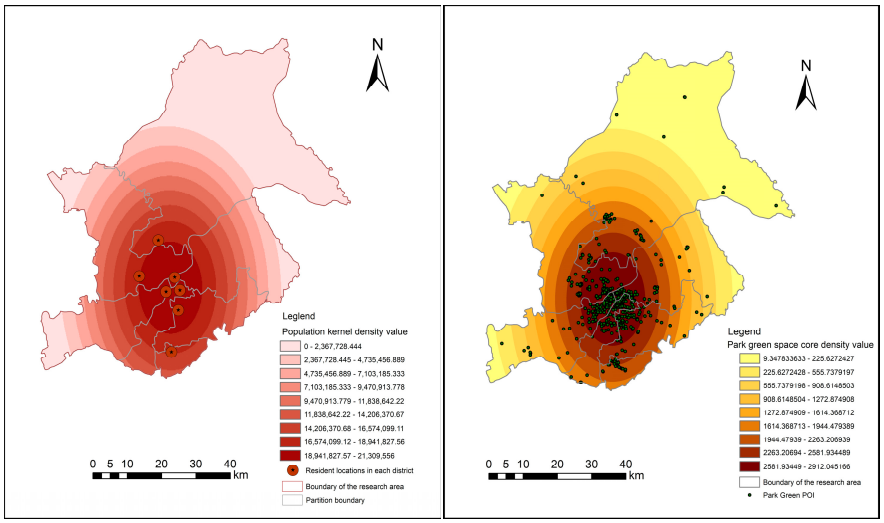


Figure 5. Population and parkland kernel density analysis map.

As shown in Table 2, Nangang District, Daoli District, and Xiangfang District accounted for 23.81%, 19.17%, and 18.79% of the gross population, respectively. The population ranked in the top three. But the per capita green area of these three main urban areas (according to the "Provisions of Urban Greening Planning and Construction Indicators", the per capita green area of parks in the districts was calculated by the formula: per capita green area of parks = green area of parks/total urban resident population) did not reach the standard of 11 m^2/person for the degree of achievement of the indicator "urban public green area" of eco-city construction, even in Nangang District. Green space per capita (calculated according to the "Provisions on Urban Greening Planning and Construction Indicators" using the formula parkland per capita = park area/total resident population) does not reach the standard of 11 m^2/person for the degree of realization of the indicator

of "public parkland per capita in cities and towns" for the construction of an eco-city, and even the parkland per capita of Nangang District is only 0.52 m^2/person. Nangang District has several shantytowns that need to be renovated, resulting in a high density in the Nangang District area. Thus, its parkland lacks cohesion, and each parkland is small, whereas the population of the allocated park green space is large, which leads to the parkland distribution of supply and demand not being up to standard. Although Hulan District is not as populous as Nangang District, it is sparsely populated, and the parkland area is relatively small, except for two clusters with more concentrated distribution; the rest of the distribution is very scattered, which leads to a per capita parkland area of only 0.70 m^2. Only Songbei District's per capita park green area has reached the target value of 11 m^2/person for the construction of an eco-city, which is an indicator of the degree of realization of the indicator, but this does not accurately represent the allocation of parkland area supply to meet the standard because the population is small. A large part of the new district has yet to be developed. Only Songbei District's park green space per capita reaches the standard value of 11 m^2/person, but this does not accurately represent Hulan District's parkland allocation because Songbei District's population is relatively small, a large portion of the new area has not been developed, and part of the parkland's single area is too large, which leads to the parkland supply in Hulan District being "falsely compliant".

Table 2. Status of the population and parkland data in the study area.

Name of Main Urban Areas (District)	Resident Population	Geographical Area (km^2)	Population Density of Main Urban Areas	Park Green Space Area (hm^2)	Green Space Area Per Capita (m^2)
Daoli	1,097,430	443.8	2472.80	905	8.25
Nangang	1,390,679	168.4	8258.18	72.8	0.52
Xiangfang	1,120,185	341.5	3280.19	418	3.73
Daowai	811,178	615.3	1317.70	509	6.27
Pingfang	238,945	92.4	2585.98	69	2.89
Hulan	769,997	2233.5	344.75	53.84	0.70
Songbei	413,515	736.8	561.23	993.21	24.02

3.1.2. Accessibility Analysis of Parkland Based on Network Analysis

The network dataset was constructed according to the previous method in Section 2.4.2 to determine the service area of the parkland, which is defined as the range of the area that can be reached from the parkland at a particular time. The reachable area of the park green space varies with different traveling modes and traveling times. According to the experimental results of previous researchers and by analyzing the actual situation in Harbin, this paper set the time thresholds for the accessibility of parkland in terms of the areas reached in 0–5 min, 5–10 min, 10–15 min, and >15 min, and classified them into four grades including excellent, good, fair, and poor for evaluation. The GIS network analysis function was used to calculate the corresponding area and its percentage.

The number of accessible settlements can reflect the relationship between service facilities and neighboring residents and is an essential indicator of the standard of urban public service due to the uneven distribution of urban settlements [38,39]. Based on the results of the accessibility analysis map (Figure 6), the parks in the survey region are mainly scattered among the seven main urban areas of the connection area. Hence, the accessibility of these areas is better, and five minutes of cycling conditions can provide better coverage of the highest density of parks and greenspaces in the entire study area. Among the three different modes of transport, the accessibility of parkland for motorized vehicles was the best, with an area ratio of 16.37% under the 15-min condition for car travel. The accessibility for walking was the worst, and the increase in the area of the parkland was slower under the different time classes, with an area ratio of only 4.12% under the 15-min condition for walking (Table 3). As the travel time threshold increased, accessibility increased for all three modes, but the corresponding increases varied widely (Figure 7). In terms of the

reachable area ratio, the walking and cycling modes increased more evenly and relatively gently at different travel time thresholds. The change in the motorized travel reachable area ratio was evident after 5 min, with a larger increase, which is a result of the more developed roadway network around the study area, resulting in a park service area that mostly coincides with the roadway network service area. In terms of the ratio of the number of reachable settlements (Figure 8, Table 4), the ratio of the number of reachable settlements in walking mode increased with time; the ratio of the number of reachable settlements in cycling and motor vehicle travel was 85.12% and 94.05%, respectively, at 10 min, which covers most of the settlements in the study area, and the increase in the ratio of the number of reachable settlements was much lower than that of 5 min. The reasons for this are as follows. Firstly, most of the settlements are covered by cycling and motor vehicles traveling at 10 min, and secondly, there are fewer settlements outside the reach of cycling and motor vehicles traveling at 5 min, and their distribution is not centralized.

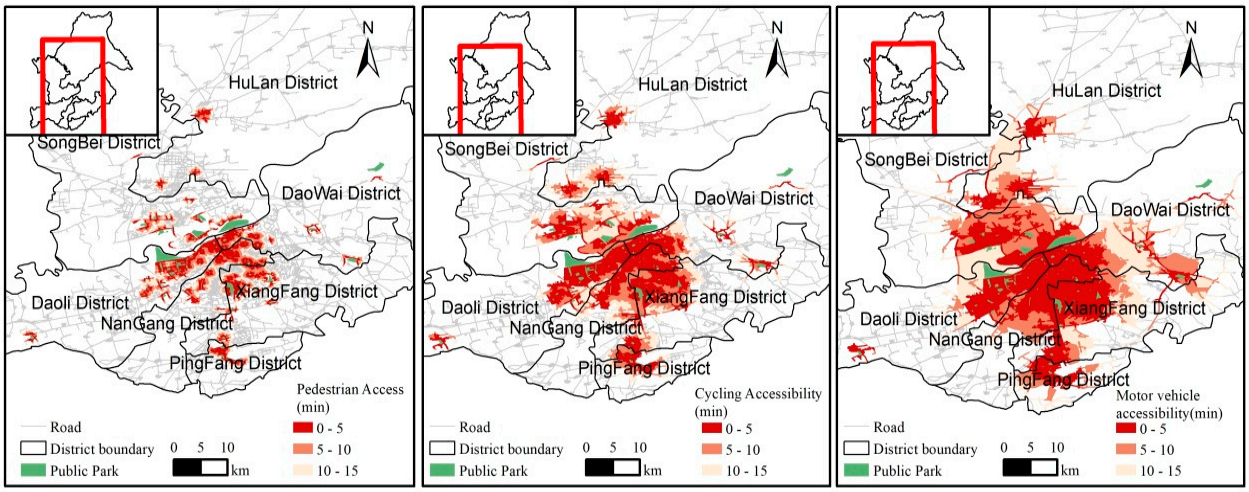


Figure 6. Accessibility of parkland by different modes of transport.

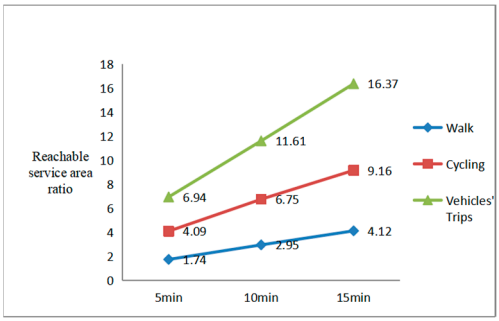


Figure 7. Trends in the growth in the reachable area ratio.

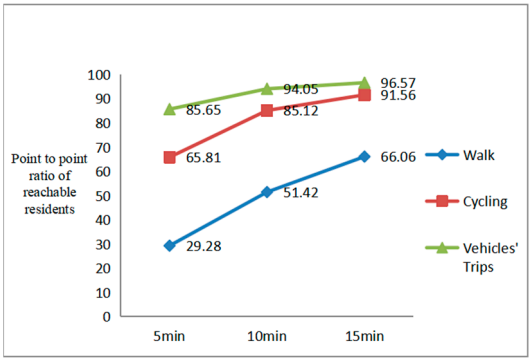


Figure 8. Trends in the number of accessible neighborhoods compared with growth.

Table 3. Accessibility ratio of different modes of transport in the main urban area.

Mode of Transport	0–5 min		5–10 min		10–15 min	
	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)	Area (km^2)	Ratio (%)
Walking	79.43	1.74	136.66	2.95	191.05	4.12
Cycling	189.35	4.09	312.78	6.75	424.25	9.16
Motorized vehicles	321.38	6.94	537.65	11.61	758.04	16.37

Table 4. Ratio of the number of accessible neighborhoods to different modes of transport in the main urban area.

Mode of Transport	0–5 min		5–10 min		10–15 min	
	Amount (size)	Ratio (%)	Amount (size)	Ratio (%)	Amount (size)	Ratio (%)
Walking	1432	29.28	2515	51.42	3231	66.06
Cycling	3219	65.81	4163	85.12	4478	91.56
Motorized vehicles	4189	85.65	4600	94.05	4723	96.57

Based on the analysis of the accessibility of the study area, the specific conclusions are as follows: the study area of parkland is too small, and the proportion of the service region covered by parkland for a 15-min motor vehicle trip is only 16.37%. The overall distribution is also uneven, with clustering at the connections between the seven main urban centers and more sporadic spreading outward. The overall accessibility within the study area is average, with the three modes of travel varying significantly in accessibility, with motorized travel being the most accessible, cycling the next most accessible, and walking the least accessible. Although 96.57% of residents can enjoy the services of the parkland within 15 min of traveling by motor vehicle, based on the field survey, for most of the residents who currently go to the parkland for exercise or leisure after meals, the probability of walking is much greater than the probability of traveling by motor vehicle. However, on the contrary, walking represents only a tiny proportion of the residents who can enjoy the services of the parkland within 15 min. There are also significant differences in the accessibility of parks and green spaces in various administrative districts. The accessibility of parkland in Daoli and Daowai Districts is better. However, in the southwestern section of Nangang District, the eastern section of Xiangfang District, and the northern section of Hulan District, even if traveling by motor vehicle, reaching the parks and green spaces in less than 15 min is almost difficult. This results from the uneven distribution of park green spaces and a need for more geographical equity.

3.2. Analysis of the Layout of Parkland under the Social Equity Hierarchy

3.2.1. Fair Analysis of Supply and Demand of Parkland and Residents Based on the Two-Step Mobile Search Method

The supply in the calculation of the supply–demand matching degree of supply is the area of parkland in the primary urban area of Harbin City. According to crawling the Gaode map of Harbin City's primary urban built-up area AOI, a total of 114 status quo parks and green spaces were extracted, with a green space area of 3020.85 hm^2, which accounted for a proportion of the city's built-up land of 0.65%, and an average per capita park green space area of 5.17 m^2 (Figure 9). The demand in the calculation of the supply and demand matching degree of demand for the population density is the 2021 Harbin City residential built-up area population of 5,841,900 people. The model sets up one to four levels of supply and demand capacity: the higher the level, the stronger the supply and demand capacity.

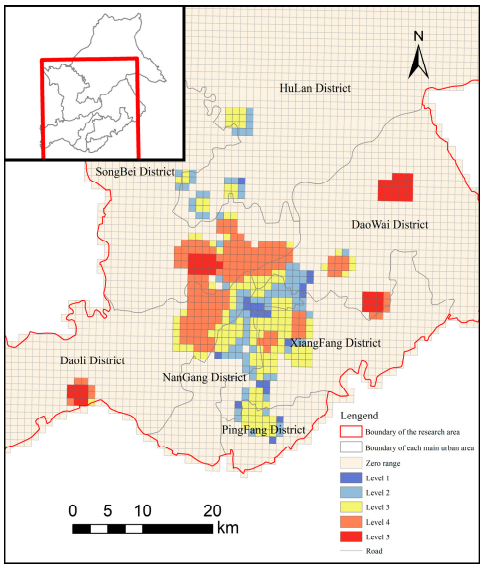


Figure 9. Matching supply and demand capacity of parkland in the survey region.

Figure 9 was obtained from the supply and demand matching degree of the first level of the supply and demand capacity zone, which accounted for 0.41%; the second level of the supply and demand capacity zone accounted for 1.85%; the third level of the supply and demand capacity zone accounted for 3.29%; and the fourth level of the supply and demand capacity zone accounted for 3.19%. The proportion of the zero-value zone accounted for 90.36% (the zero-value zone exists in the figure where there is no population living in the range or there is no parkland in the area, resulting in the degree of supply or demand being zero) of which, except for the zero-value area of the third level of supply and demand capacity accounting for the highest proportion, most of the area is higher than the per capita parkland area in the primary urban area of Harbin City. With the exception of Daoli and Xiangfang Districts, the other five districts have a correspondingly low parkland supply and demand capacity, or it is lower than the per capita parkland area of the main urban area of Harbin, and most of them have a level 3 supply and demand capacity, including Daowai District. However, there are two districts that show a level 5 capacity, the reason for this is that the population of the two level-5-capacity districts is relatively small, and the same applies to Daoli District (Figure 9).

3.2.2. Supply and Demand Equity Analyses of Parkland and Vulnerable Groups

(1) Analysis of Parkland and Overall Equity of Residents Based on the Lorenz Curve and the Gini Coefficient

This paper uses the Lorenz curve and the Gini coefficient to study the overall fairness of the planning of parkland resources among regional residents and the degree of distribution. The Lorenz curve measures the per capita share of park green space resources; the Gini coefficient illustrates the degree of match between park green space resources and residents.

As can be seen from the Lorenz curve diagram, the actual park green space allocation line is far away from the absolute average line, especially in the middle part, which has the most significant distance from the average line, so there is a vast difference in the overall allocation of parkland in the central section of Harbin. As can be seen from the figure, the first 43 percent of the population enjoys less than 10 percent of the total amount of parkland services. The last 30 percent of the population enjoys 50 percent of the parkland. Therefore, there is a clear gap between the two parks' green space distribution levels in the central section of Harbin. The enjoyment of parkland in the central city of Harbin could be better from a social point of view, and social equity could be higher.

According to the relationship between the Gini coefficient and the Lorentz curve, the Gini coefficient of park green space resource allocation is calculated by the geometric

method, and its value is 0.407. Comparing it with the Gini coefficient classifications of the United Nations, classifications with Gini coefficient values ranging from 0.4 to 0.59 belonged to the more significant gap. However, the Gini coefficient can only reflect the overall equity of the distribution of park resources among residents in the study area; it cannot precisely express the relationship between disadvantaged groups and the planning of parkland among all residents. Therefore, it is necessary to draw on the share index and the method of location entropy to express the specific equity relationship between the disadvantaged groups (the elderly and children, for example) and the park's green space resources.

(2) Share Equity Analyses Based on the Older Age Group and the Child Group

The World Health Organization (WHO) has released a new age criterion based on measuring human fitness and life expectancy worldwide, which defines people over 60 as elderly. According to the International Convention on the Rights of the Child, a child is defined as a person under 18. Based on the seventh population census of Harbin and the 2021 Statistical Yearbook of Harbin, data on the elderly population over 60 years old and children aged 0–17 years old in Harbin were obtained in this paper.

The data in Table 5 shows that Nangang and Daoli Districts have the most significant proportion of older adults at 22.64 percent and 20.86 percent, respectively, and have entered the stage of moderate aging. The next is Xiangfang District and Daowai District, where the percentage of the aged population is 17.47% and 17.19%, respectively. Based on the field survey analysis, the reason why the degree of aging is heavier is because these districts are primarily old urban areas, and because of the familiarity of the living environment, some of the older residents chose not to move to a new home. Meanwhile, Daoli and Nangang Districts also have the highest percentage of the child population at 16.50 percent and 9.06 percent, respectively, which is primarily due to the relatively better educational resources and better medical protection facilities for children in these two districts.

Table 5. Data on the status of the elderly population and child population in the study area.

Study Area (District)	Elderly Population	Elderly Population as a Percentage of the Main Urban Area	Child Population	Child Population as a Percentage of the Main Urban Area
Daoli	228,927	20.86%	99,453	9.06%
Nangang	248,504	22.64%	181,064	16.50%
Xiangfang	191,756	17.47%	95,229	8.68%
Daowai	188,672	17.19%	61,069	5.56%
Pingfang	44,225	4.03%	17,203	1.57%
Hulan	141,198	12.87%	79,162	7.21%
Songbei	51,279	4.67%	39,261	3.58%

By analyzing the above data and combining them with the formula, the share index of the elderly is 0.299, and that of children is 0.137. Both of these values are smaller less than 1, indicating that the level of parkland resources in street parks enjoyed by the disadvantaged groups of the elderly and children is lower than the balance level of parkland resources in street parks enjoyed by the population as a whole. Comparing these two values with the share index "1", it can be concluded that there is a large gap between these two vulnerable groups and the average social equity requirements. Overall, the level of service for the elderly and child-disadvantaged groups in the central city of Harbin in terms of access to regional parks and green space resources needs to be significantly improved.

(3) Equity Analyses of Locational Entropy Based on the Older Age Group and the Child Group

The share index can only determine whether the level of enjoyment of parkland resources for the elderly and child groups within the study area is fair or not, so we further use the locational entropy formula to analyze the spatial pattern of social fairness for

the elderly and child groups. Using the social fairness evaluation formula, we analyze the degree of enjoyment of parkland for the elderly disadvantaged group and the child-disadvantaged group in the central city of Harbin City. We use the natural intermittent point grading method to classify the locational entropy of the elderly and child groups into seven categories. We carry out the spatial visualization in a GIS. The ratio of parkland per capita in each area to parkland per capita within the study area as a whole is derived to determine whether the enjoyment of resources by the population in each neighborhood is socially equitable.

From Figure 10, it can be seen that the elderly disadvantaged group has the highest entropy value for the overall park green area location in Songbei District, followed by Daoli District. The child-disadvantaged group has the highest entropy value for the overall park green area location in Xiangfang District, followed by Songbei District. This indicates that the per capita enjoyment of parkland resources in these areas is above average within the survey region, with the elderly population in Dori District accounting for 20.86 percent of the total population of Dori District, and the high per capita enjoyment of parkland resources in Dori District because of its large number of parks and green spaces and its large area. The highest entropy value of the child group for the overall park green space location in Xiangfang District is due to the relatively low density of the child population in Xiangfang District, which is richer in park green space. In Songbei District, although the elderly and child populations are smaller, the parkland distribution of Songbei District has a large individual area, resulting in a higher per capita enjoyment of parkland resources. The field survey and data show that Nangang District has vulnerable elderly groups and vulnerable child groups per capita, and the minimum public green space service level district entropy value is because Nangang District's local experience of shantytown renovation and high density of residential housing, parks, and green space construction are relatively lagging.

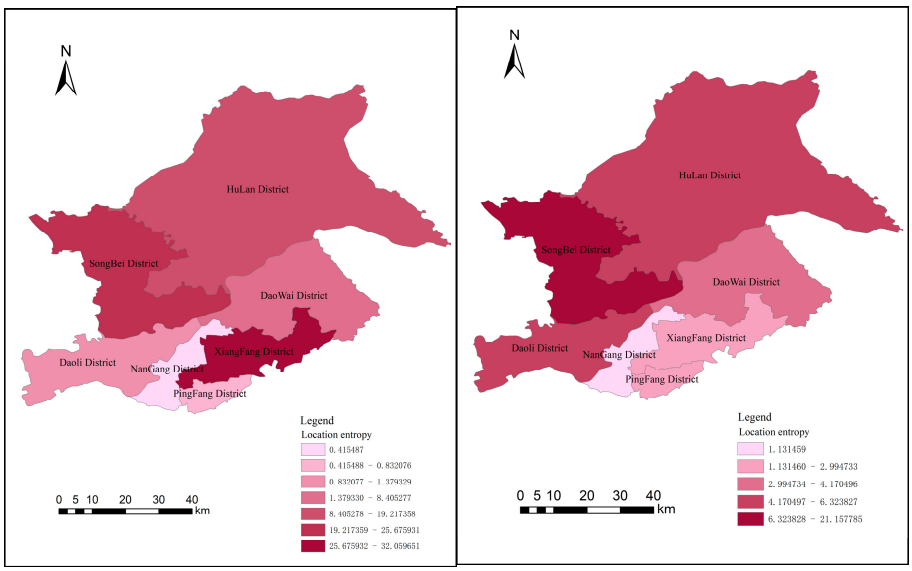


Figure 10. Spatial distribution of entropy values of the location of elderly disadvantaged groups and child-disadvantaged groups for the overall park green area.

In summary, the matching analysis of the disadvantaged groups of the elderly and children in different streets from location entropy reveals that the location entropy is both high and low under different areas, and the reasons for the extremely high or low location entropy are also different. For example, the location entropy is extremely low when the number of elderly disadvantaged groups and child-disadvantaged groups is high, and the spatial units with intensively low location entropy usually refer to the relatively densely populated old urban areas or shantytown renovation areas, such as the Workers' New

Villages and similar areas. These regions have a high-density of resident population and a relative handful of public green space. Conversely, new industrial parks or new residential areas are often newer urban development areas where relatively more public green space is built. However, the density of the resident population is lower, leading to a high entropy for the district. By studying social equity, we can gradually establish social justice performance based on spatial matching, and the planning of urban public parkland should be tilted toward concrete social groups to safeguard the interests of socially disadvantaged groups.

4. Discussion

4.1. The Influence of the Accessibility of Parkland on the Equity of Parkland

The accessibility analysis in this study highlights the uneven distribution of parkland in different areas of the city and reveals the restrictions on access to public parkland in specific areas. Our findings echo those of Yongxiang Ye et al. [40], who, by measuring the spatial distribution of parks, found that the accessibility of parkland in a city is closely related to the travel status of residents. In addition, our results support the study by Jianjun Yang et al. [41], which quantified the accessibility of urban green spaces and indicated that walking modes of travel often face greater park accessibility challenges. By using GIS technology and network analysis methods, our research further deepens the quantitative understanding of the accessibility of parkland. This approach is similar to that adopted by Mengqi Wang et al. [42] in their study using GIS technology to assess the accessibility of parkland to community members, which highlighted the importance of parkland in promoting public health and community well-being. Our research expands the knowledge in this area, revealing the potential and challenges of urban planning in improving the equity of parkland using more detailed spatial analysis. Moreover, our study on the level of spatial equity found that the large difference in the accessibility of parkland and the imbalance between the supply and demand of parkland are the main reasons for the imbalance of parkland equity in the main urban area of Harbin.

Taken together, our accessibility study not only confirms the findings of previous research that the accessibility of urban parkland varies significantly between neighborhoods, but it also provides new insights into how equity in parkland can be more fully assessed by taking into account the quality, size, and needs of different modes of travel. These findings provide important information for city planners and policymakers to help them design more equitable and inclusive parkland planning strategies.

4.2. The Impact of Supply and Demand Balance on the Social Equity of Parkland

This study evaluates the balance of supply and demand in parkland by considering the supply of parkland comprehensively. This methodology is closely related to the work of Wei Wei et al. [43], who emphasized the importance of achieving a balance between supply and demand in urban planning by assessing the spatial distribution of parkland in urban residents' demand for access to parkland. Our analysis further confirmed the significant differences between parkland supply and community demand, especially in shantytowns and marginalized areas, and found that the coordinated development of parkland in the study area was poor. Indeed, about 50% of the regions had insufficient supply and demand capacity, the development speed and direction of supply and demand were low, and urban high density exacerbated the inequity of regional parkland allocation. In addition, our results support the findings of Zhao Yang et al. [44], which indicated that the supply–demand balance analysis of urban parkland reveals the impact of development process factors on parkland accessibility. Our data analysis shows that less developed areas tend to face a greater undersupply of parkland, which is consistent with their findings that unplanned and undeveloped areas tend to lack sufficient public parkland resources. We also refer to the work of Jiawei Zhou [45], who used a supply and demand model to measure the unequal distribution of urban parkland services. By comparing our results with their findings, we further highlight the need to strengthen urban parkland planning

and management strategies to ensure that all regional residents have equitable access to high-quality parkland resources.

To sum up, the supply–demand balance study in this study echoes previous research both theoretically and methodologically while also providing new insights and evidence to support the need to improve urban parkland planning and management, especially when considering different demands for parkland in different regions. These findings provide a valuable reference for future research and practice, especially in exploring how to improve the quality of life of urban residents with the equitable distribution of parkland.

4.3. The Influence of Vulnerable Groups' Access to Parkland Resources on Social Equity of Parkland

This study reveals the fairness of green space in cities by analyzing the visits of groups of different social backgrounds to park green space. In particular, we looked at disparities in access to high-quality green space for vulnerable groups, including the elderly and children. This analytical framework echoes the work of Du Yi and Liu Kaikai [46], who pointed out that the social distribution of green space services is uneven, highlighting the importance of considering green space equity in urban planning. Our results show that while parkland in cities is theoretically open to all residents, in practice, access to parkland is much lower among disadvantaged groups than among other groups. This finding is consistent with research by Yajie Zou et al. [47], who found that lower-social status groups were less involved in outdoor activities, partly due to the poor accessibility of green space resources.

By comparing the findings of this study with the work of Huang Shuhe et al. [48], we further emphasize the need for inclusive strategies in parkland planning and management. Huang Shuhe et al.'s study suggests that in order to improve the equity of urban parkland, special consideration should be given to the needs and preferences of vulnerable groups. Our analysis supports this view and suggests specific strategies, such as considering the special needs of the elderly and children in parkland design and improving the quality and quantity of parkland in low-income communities.

To sum up, this study forms a useful dialogue with previous studies in the analysis of the degree of parkland enjoyed by disadvantaged groups. Not only do we confirm the inequity of parkland access across different groups in society, but we also make targeted recommendations to promote a more equitable distribution of parkland. These findings have important implications for guiding future urban parkland planning and policymaking, particularly in efforts to achieve a more equitable and inclusive urban environment.

5. Conclusions

As an important part of the urban ecosystem, parkland has direct and indirect positive effects on residents' physical and mental health. More and more scholars are considering parkland and mental health in cross-field research, and research shows that exposure to natural environments can reduce psychological stress, improve mood, enhance physical vitality, and reduce the risk of chronic diseases [49]. However, from the perspective of spatial equity in this paper, these health benefits are not equally enjoyed by residents in different regions, especially in marginalized regions. Therefore, assessing the fairness of the distribution of parkland in different regions is of great significance for improving the health of the whole people.

Parkland provides numerous spaces for leisure and social activities, contributing to the quality of life and happiness of residents. Parklands are an important part of community life, providing a place for people to gather with family and friends and engage in outdoor activities. However, this study found that groups with lower social status often have difficulty in obtaining high-quality parkland services, which not only affects their physical and mental health but also limits their opportunities for social interaction and aggravates social inequality. Therefore, from the perspective of social equity, optimizing the spatial layout of parkland to serve all areas more equally is the key to improving the overall

well-being of urban residents. Parklands are also important sources of social cohesion in cities. By providing shared spaces for people of different backgrounds and cultures, parklands promote communication and understanding within and between communities, thus enhancing social inclusion and diversity. However, if the layout and distribution of parklands are unfair, certain communities may be marginalized and unable to participate fully in community activities, thus weakening the overall cohesion of society. Ensuring equitable access to parkland is therefore essential to building and maintaining strong community relations and social cohesion.

In addition, according to the research results, in the future layout of parkland, a large range of parkland can be built by aiming at the relatively low population density area around the city and relying on the existing natural landscape conditions. The spatial layout of urban green geology and quantity can be changed by connecting corridor parkland with flake green space in the central city, or by increasing small and micro-parklands and vertical greening in the central city. This can increase the connectivity between parks and improve the service area of urban parks. Moderate planning and construction of urban parks can increase the supply of urban parks in each region. However, considering that many areas are old urban areas with a high degree of construction, it is usually difficult to add new large parks in terms of space. We suggest adopting urban micro-renewal and fragmented reconstruction to improve the accessibility of existing parks. For the situation where the road network in old urban areas is difficult to build, it can increase the entrances and exits of parks, improve the openness of parks, and reduce the time cost of residents using parks.

Based on the analysis of the accessibility results of the parkland, large-scale, high-quality parks can be reached by expanding the service area of parks; focusing on enhancing the surrounding transport environment; improving the convenience of public transport to reach the various parklands at public transport hubs in Harbin City; and increasing the amount of land used for transport in the vicinity of such attractions and highlighting the advantages of their high accessibility by public transport, where there is a large base of older adults and a low fairness performance index, and where the transport system can be enhanced by appropriately augmenting the quantity of public transport stops and underground feeder buses, to enhance the ease with which disadvantaged groups. In addition to public transport and walking, traveling with children is biased toward car modes, and a prominent contradiction between the supply and demand of parking spaces and an unreasonable supply structure highlights parking difficulties near the park. Bus stops and street signs can be installed near the entrances and exits of parks, and the surrounding footpaths can be repaired to facilitate walking and non-motorized travel for residents. In conjunction with territorial spatial planning, we recommend applying scientific and rational means for park layout, giving full play to urban parks' ecological value and service functions, and setting up flexible space for parkland to avoid the encroachment and reduction of urban parkland.

Constrained by data and other factors, this study also has certain shortcomings. Future research should include the quality of accessible parkland as an evaluation factor in the exploration of spatial equity. Future research should also aim to understand the psychological needs of users through questionnaires and interviews, evaluate the quality of parkland through satisfaction scoring, and incorporate park accessibility characteristics into the research framework in order to enhance the accuracy of this study.

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