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*Article*

# Beyond Accessibility: A Multidimensional Evaluation of Urban Park Equity in Yangzhou, China

**Zhiming Li [1,*], Zhengyuan Liang [1], Linhui Feng [1] and Zhengxi Fan [2]**

[1] College of Landscape Architecture, Nanjing Forestry University, Nanjing 210037, China; liangzhengyuan@njfu.edu.cn (Z.L.); fenglinhui0110@njfu.edu.cn (L.F.)
[2] College of Architecture, Southeast University, Nanjing 210096, China; fanzx0058@seu.edu.cn
* Correspondence: lizhiming7507@njfu.edu.cn

**Abstract:** Evaluating park equity can help guide the advancement of sustainable and equitable space policies. Previous studies have mainly considered accessibility when evaluating park equity while ignoring the selectivity and convenience of entering parks and residents' recognition of parks. Measuring equity based mainly on spatial thinking has resulted in the social aspects of parks receiving insufficient attention. In this study, we therefore integrated the spatial and social equity of parks and developed a multidimensional framework to evaluate park equity in four dimensions: accessibility (*Ai*), diversity (*Di*), convenience (*Ci*), and satisfaction (*Si*). Empirical analysis from Yangzhou, China showed that: (1) in Yangzhou's built-up districts, 23.43% of the communities received high- or relatively high-level park access but 17.72% received little or no park access. (2) The Gini coefficient indicated that all three dimensions showed a mismatch with population distribution, except for satisfaction (*Si*), which showed a relatively reasonable match. (3) Park access was generally better in communities with better locations, environments, and facilities. High-income groups enjoyed significantly better park access than low- and middle-income groups. These findings could help urban planners and policymakers develop effective policies to reduce inequality in park access.

**Keywords:** park accessibility; park access; park equity; spatial justice; sociospatial dialectics; multidimensional evaluation



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## 1. Introduction

The COVID-19 pandemic has posed a global health threat [1]. Urban green spaces (UGSs) play vital roles in air purification, climate regulation, environmental monitoring, and habitat improvement, and they are also closely linked to public health [2–4]. Moreover, UGSs provide opportunities for various types of leisure activities and can encourage physical activity and social interaction among residents, thus reducing stress and improving physical and mental health [5,6]. As a form of UGSs, urban parks are constructed using public funds in China. Therefore, urban residents are entitled to equally enjoy the park's benefits [7]. Can parks always be equitably distributed in cities? This question pertains to the "green rights" of urban residents, especially vulnerable groups.

Park access is the residents' right of using urban parks [8]. Park equity means all residents have equal park access regardless of class, income, or race [9,10]. Since availability and spatial distribution significantly affect residents' use, research on park equity is often focused on measuring accessibility [11,12]. The development of geographic information systems (GIS) has led to three main types of GIS-based accessibility measures: (1) Statistical index methods, which measure the number, size, or density of parks in defined geographic areas; (2) spatial proximity methods, which measure the travel costs, including the time, distance, or monetary cost, to enter parks; and (3) spatial interaction models, which measure the matching degree between park size (supply side) and population (demand side) [13]. The second type of these three methods is based on spatial distance and is the most widely used, e.g., as buffer analysis [14], network analysis [15–17], and cost-weighted distance analysis [18]. In recent years, GIS has enabled the leap from Euclidean distances to traffic network distances in park accessibility calculations. Based on network distances and park entrances, GIS can provide more realistic and reliable accessibility measures.

The Two-Step Floating Catchment Area (2SFCA) method combines the advantages of the three types of calculation methods while flexibly processing the influence of factors such as network complexities, travel modes, distance thresholds, and destination choices on accessibility [13,19,20]. Considering park size (the supply capacity of the supply point) and the population (the demand scale of the demand point), this method takes residents' homes as the starts and park entrances as the destinations, and based on the network distances, the per capita park accessible area within a certain threshold distance is used as a measure of accessibility. Currently, 2SFCA and its improved models have become some of the most popular methods for park equity analysis. However, although such models have advanced beyond the work of earlier studies that mainly measured park equity in terms of number and size, they are still mostly based on location and GIS-based analyses that do not consider other factors of park access, including non-distance factors [8,11,21]. Accordingly, the authors of several studies have attempted to work beyond the conceptual constraints of accessibility and add other dimensions to measure park equity, such as perceived accessibility, service quality, and crowding [11,22–24]. There is still much room for improvement in the choice of dimensions and the design of frameworks in this domain of research.

In this study, we therefore developed a multidimensional evaluation framework for urban park equity that moves beyond accessibility (*Ai*) to include three additional dimensions: diversity (*Di*), convenience (*Ci*), and satisfaction (*Si*), where *Si* is a subjective dimension. The rest of this paper is organized as follows. In Section 2, we review previous studies and their limitations and develop a new methodological framework. In Section 3, we present the details of the study area and data considered for analysis in this study. In Section 4, we present the study methods, and in Section 5, we present the empirical results of the study, taking Yangzhou as an example. In Section 6, we discuss the findings and limitations of the study. In Section 7, we present the main conclusions of our study.

## 2. Theoretical Framework

### 2.1. Traditional Evaluations of Park Equity Based on Park Accessibility

Public facilities such as UGSs are spatially separated from their users and are usually located in fixed locations, so accessibility is a crucial indicator for addressing the issue of equitable allocation [12]. Accessibility is usually defined in terms of the proximity of one place to another—an objective variable in two-dimensional space based on geographic distance [25,26]. With the development of GIS, urban researchers have improved the measurement models for park accessibility, of which 2SFCA and its improved models are the most commonly used. However, 2SFCA neglects the process of distance decay and assumes that residents within a catchment have uniform access [27,28]. Researchers have devised various solutions to this limitation, including gravity 2SFCA [29] and Gaussian 2SFCA (Ga2SFCA) [12,30], which are based on an expansion of the introduction of the decay function. Variable 2SFCA [31] and dynamic 2SFCA [32] are based on an expansion of search radius. Hierarchical 2SFCA [33], travel behavior-based Ga2SFCA [27], and commuter-based 2SFCA [34] are based on an expansion of the travel mode. Three-step floating catchment area [35,36], Huff 2SFCA [37], and enhanced 2SFCA [38,39] are based on an extension of demand or supply competition.

Park equity is affected not only by its accessibility but also by other attributes such as its function, type, landscape quality, facilities, park maintenance, and public perception [8,40,41]. Rethinking the accessibility, use, and behavior of urban parks, Wang (2015) measured park equity in five dimensions of accessibility: people accessibility, perceived accessibility, place use behavior, nonuse behavior, and place accessibility. According to that study, subjective (perceived) and objective (geographic) measures of accessibility are significantly incompatible. The authors of some studies have attempted to measure park equity beyond accessibility, and park quantity, size, and quality are often used together with accessibility as evaluation indicators [10,42,43]. In addition, some researchers have used indicators such as the shortest distance to parks, the number of parks within a given distance or unit, and park area per capita to describe park characteristics [23,44]. Such evaluation indicators were selected based on different park use behaviors; therefore, the results have often differed, even producing contradictory conclusions [22,45]. Summarizing the shortcomings of previous studies, Yuzhen et al. (2021) developed a framework for evaluating park equity based on four dimensions: convenience, congestion, diversity of choice, and service quality. Convenience was expressed as the closest distance between originations and destinations, congestion as the park area, diversity of choice as the number of parks that can be accessed within a certain distance, and service quality as visitor-review data [22,46]. However, they were still found to be inadequate in the selection of dimensions.

A literature review suggests that facilitated by the spatial analytical capabilities offered by GIS and the availability of spatial and activity data, accessibility (distance cost, time cost, economic cost, etc.) is often considered to be the main dimension used to evaluate park equity [27,47,48]. However, accessibility ignores the following questions: How many choices do residents have in using parks? Which parks are the most convenient for residents? Are residents satisfied with park service quality? These factors also significantly affect park access and should be considered. To deal with the limitations, our framework considers four dimensions of accessibility, diversity, satisfaction, and convenience to measure park equity. Of these, accessibility is calculated based on network distance and diversity and convenience represent park users' right to freely choose to enter a park and the distance to the nearest park, respectively. Satisfaction comes from residents' independent comment data.

### 2.2. Multidimensional Evaluation Framework of Park Equity Based on "Sociospatial Dialectics"

Park equity is a hot topic in the field of spatial justice [9,48–50]. In geographic research, this topic is mostly studied from the perspective of equity in spatial distribution, and other studies have been focused on social inclusion and justice. Spatial justice is a combined concept of social justice and space [15,48,51]. In the geographical field, justice is occasionally discussed in relation to spatial processes (such as globalization, urbanization, suburbanization, gentrification, migration, environmental disturbance, and harm) that can lead to social consequences such as inequity, segregation, exclusion, and avoidance [51–53]. Therefore, an impartial standard is needed to explore the social consequences of different spatial phenomena to guide the advancement of sustainable and equitable space policies [51,54]. What social indicators are needed to measure the equity of UGSs? Policy tools, capital resources, etc., determine the opportunities of park access enjoyed by different social groups, thereby affecting spatial equity (i.e., social equity) [55,56]. Thus, the spatial equity of parks can be generalized as equity of opportunity distribution; social equity allows for further consideration for different socioeconomic groups.

Researchers have different priorities for the spatial and social equity of parks. Some scholars pay more attention to spatial equity and evaluate whether park distribution is equitable by studying the matching degree between park indicators and population [27,28,57,58]. For example, Hu et al. (2020) integrated different travel modes (walking, public transportation, and car modes) and park attractiveness coefficients into the Gaussian 2SFCA model, and they confirmed the inequitable distribution of parks through a bivariate Moran's index between accessibility and population density [28]. Other scholars focus on social equity, and different population stratification data such as race, age, income, and education help them analyze park equity for vulnerable groups [50,59–63]. However, limited by the difficulty of obtaining community-level population stratification data, research on social equity is far from sufficient. Additionally, almost no research has yet incorporated spatial and social equity as a whole into a comprehensive framework for evaluating park equity.

Proposed by Lefebvre (1991), the concept of "sociospatial dialectics" suggests that space is more than a geometric and traditionally geographic concept. Rather, it is a dynamic, contradictory, and heterogeneous process of practice, wherein society constitutes space, society is constructed by space, and space is a product of society—not just a product but also a process of reorganizing social relations and building up social order [64]. Havens (2017) suggested that parks are the "medium of nation-formation" in modern Japan—a medium between human culture and nature, a medium for communication between the government and the people, and a place of conflict between the two. Natural and social systems are intertwined. A park is a medium of interaction between society and space, a cyclical process in which space serves society and is then fed back to and amended by society [65,66] (Figure 1). Many studies, however, have been focused on spatial characteristics, such as structure and distribution, while neglecting the social, economic, and environmental characteristics of communities [56,67–69]. By treating people as undifferentiated, abstract individuals, the park access of disadvantaged groups is often ignored [62,70–72]. Therefore, an evaluation framework for evaluating park equity that considers both spatial and social equity urgently needs to be developed.

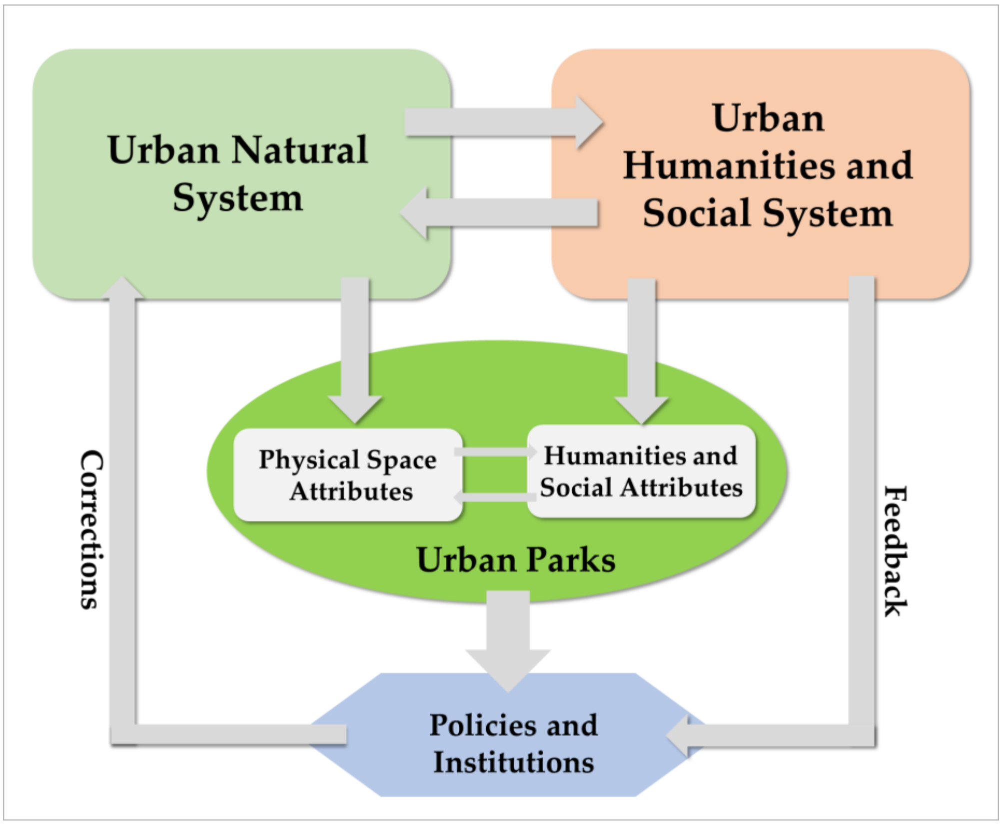


**Figure 1.** Interaction between natural and social systems.

Based on "sociospatial dialectics", we developed a comprehensive framework that incorporates the spatial equity and social equity of parks (Figure 2). Four dimensions were selected for measurement: accessibility (*Ai*), diversity (*Di*), convenience (*Ci*), and satisfaction (*Si*). Specifically, we aimed to: (1) establish a framework for evaluating park equity in multiple dimensions, (2) analyze equity in the spatial distribution of parks and differences in the enjoyment of parks by different social groups, and (3) provide suggestions for governments to rationally plan and manage parks so that urban residents can equally enjoy park access.

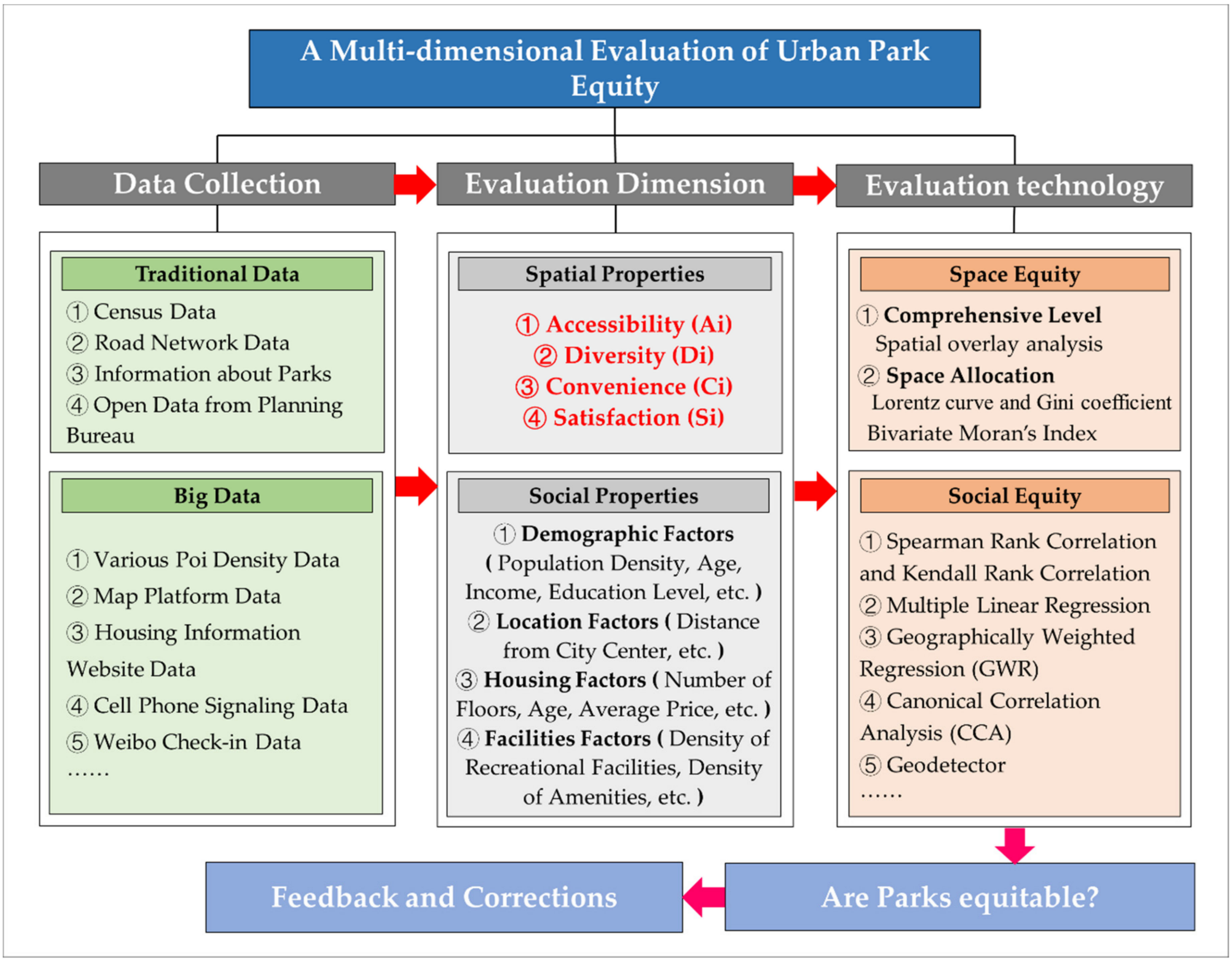


**Figure 2.** Multidimensional evaluation framework of urban park equity.

## 3. Study Area and Data

### *3.1. Study Area and Basic Data*

We used Yangzhou, China, as an example for analysis. Yangzhou includes three districts, one county, and two county-level cities under its administration; it has a total area of 6634 km$^2$ and a resident population of 4,600,500 [73]. It is an internationally recognized garden city. As of September 2019, Yangzhou had 322 parks, including 37 comprehensive parks, 185 community parks, 13 linear parks, 28 special parks, and 59 pocket parks, as well as 18.57 m$^2$ of green space per capita. According to the "Special Plan for the Development and Protection of Yangzhou Park System (2018–2035)", comprehensive parks include city-level and district-level comprehensive parks, which refer to green spaces with rich content, complete functions, and complete facilities, providing leisure and entertainment for residents and having a certain scale. Community parks refer to green spaces with independent land use, as well as basic recreational and service facilities, and they are mainly used by residents in certain communities to carry out daily leisure activities. Specialty parks refer to green spaces with specific contents or forms and corresponding recreational and service facilities, mainly including zoos, botanical gardens, heritage parks, amusement parks, historical parks and other special parks. Pocket parks are small urban open spaces, often scattered in patches or hidden within the urban fabric, to serve nearby residents [74]. The classification of Yangzhou's parks is shown in Table 1.

**Table 1.** Park classification in Yangzhou.

| Park Classification | | Size |
|---|---|---|
| Comprehensive Park | City level | Above 20 $hm^2$ |
| | District level | Above 10 $hm^2$ |
| Community Park | | Above 0.5 $hm^2$ |
| Pocket Park | | Above 0.2 $hm^2$ |
| Specialty Park | Zoos, botanical gardens, children's parks, historical parks, amusement parks and scenic areas | Depends on the actual situation |

According to the Yangzhou Master Plan (2008–2020) [73,75], owing to the large extent of Yangzhou's central districts, there is still a large amount of land collectively owned by peasants. Therefore, Yangzhou's built-up districts were selected as the study area [75]. These are nonagricultural production and construction areas with relatively good public facilities, and they include Hanjiang, Guangling, and Jiangdu, which comprise an area of 241.5 $km^2$ and have 28 streets and 175 communities (Figure 3).

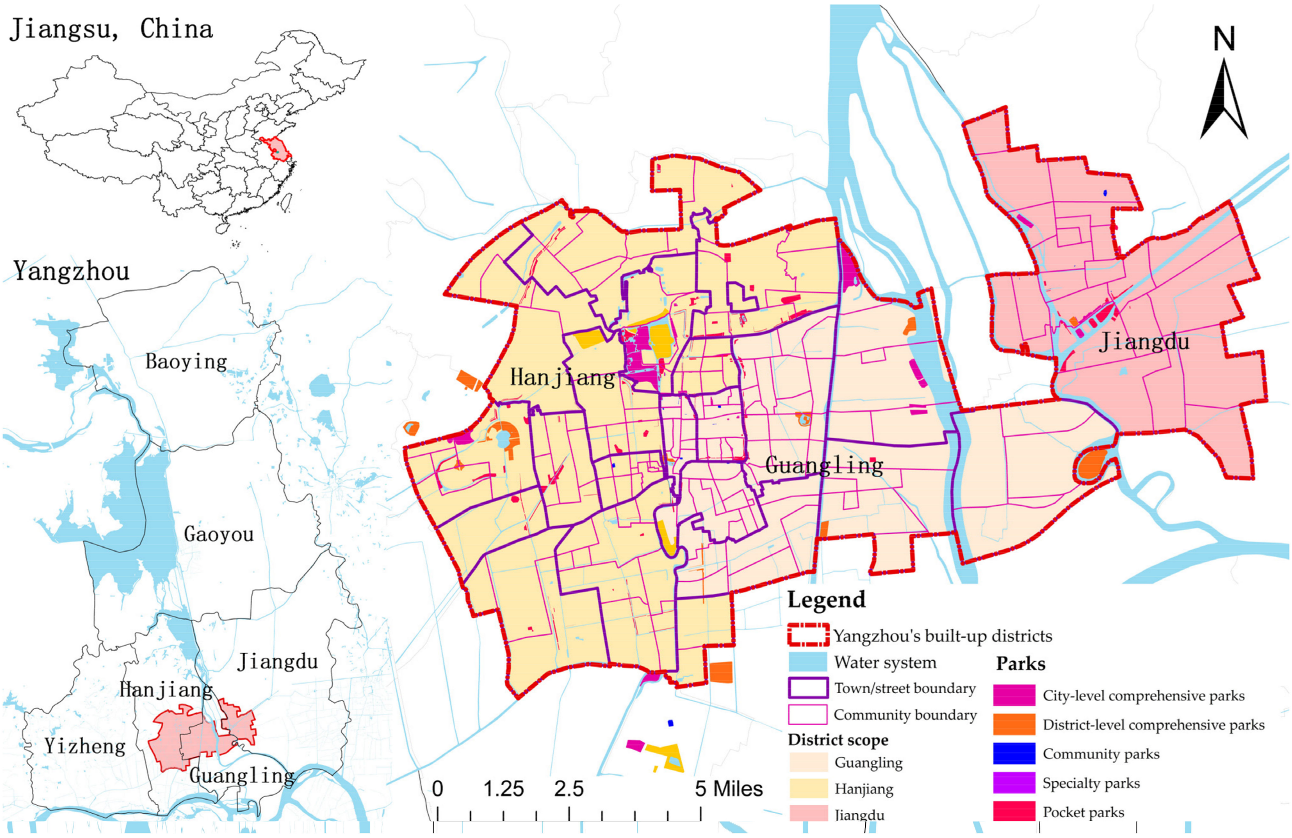


**Figure 3.** Study area and park location.

Basic data were mainly obtained from the following sources: (1) road network data from the Yangzhou Municipal Bureau of Transportation, (2) park locations and details from the Yangzhou Municipal Bureau of Landscape Architecture, and (3) community population data from the Sixth National Census of the People's Republic of China (Figure 4).

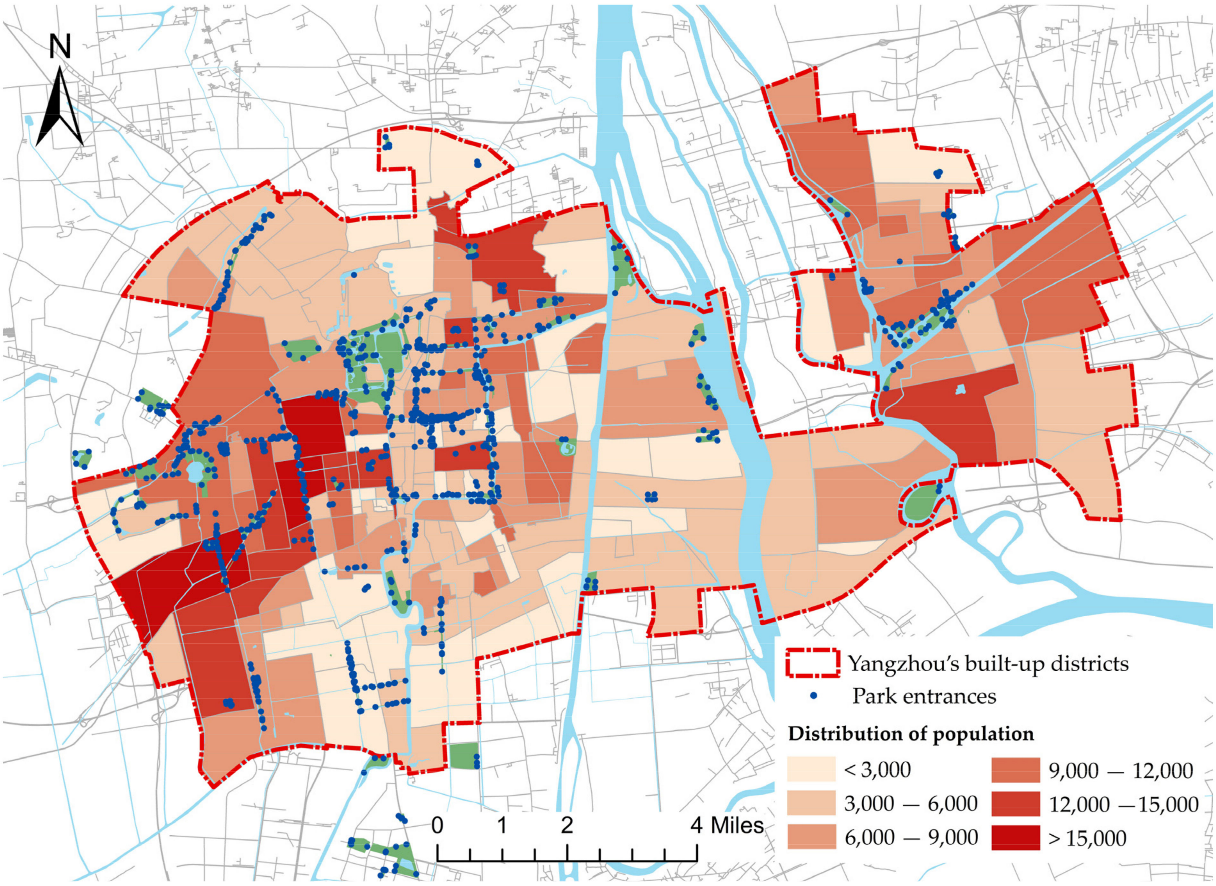


**Figure 4.** Park entrances and population distribution.

### 3.2. Variables

Two types of variables were used in this study (Table 2). One included four dimensions of park access levels, the details of which are further explained in the variable calculation section. The other included variables related to the social, economic, and environmental properties of the community. Table 2 shows the specific information of the variables. The data on housing prices were sourced from the largest housing transaction website in Yangzhou: https://yz.esf.fang.com (accessed on 23 January 2020). The data of points of interest were crawled from the open platform of AutoNavi map: https://lbs.amap.com (accessed on 25 January 2020) through the python interface before being further filtered and classified.

**Table 2.** Variable information.

| Variable Type | Variable Nature | Variable Name | Variable Interpretation | Variable Source | Unit |
|---|---|---|---|---|---|
| Variables of multiple dimensions | Objective variable | Accessibility (*Ai*) | Per capita park area reachable within 30 min walking distance | Calculation based on SD-KD2SFCA | per m$^2$ |
| | | Diversity (*Di*) | Number of parks accessible within 30 min walking distance | Statistics based on network analysis | — |
| | | Convenience (*Ci*) | Network distance to the nearest park | Calculation based on network analysis | m |
| | Subjective variable | Satisfaction (*Si*) | Residents' review | Statistical analysis of 672 questionnaires | — |
| Variables of community properties | Demographic property | Population density (X1) | Ratio of community population MILOSto community area | From China's sixth census | per m$^2$ |
| | Location property | Distance from the city center (X2) | Distance from the community to the city center (Wenchang Pavilion) | Calculation based nearest-neighbor analysis | m |
| | Housing property | Average number of residential buildings (X3) | Average number of floors for all housing | Crawling from: https://yz.esf.fang.com (accessed on 23 January 2020) | floor |
| | | Housing prices (X4) | Average prices of all housing | | yuan |
| | Facility property | Density of points of interest for public transportation facilities (X5) | Ratio of the number of parking lots, bus stops, gas stations, and other facilities to the area of the community | Crawling the open platform of AutoNavi map: https://lbs.amap.com (accessed on 25 January 2020) | per m$^2$ |
| | | Density of points of interest for leisure and entertainment facilities (X6) | Ratio of the number of bathing centers, chess and card rooms, ecological farms, resorts, and other facilities to the community area | | per m$^2$ |
| | | Density of points of interest for living facilities (X7) | Ratio of the number of restaurants, shopping malls, vegetable markets, and other facilities to the community area | | per m$^2$ |

## 4. Methods

### *4.1. Four Dimensions of Measuring Park Access Levels*

#### 4.1.1. Accessibility (Ai)

The 2SFCA method was first proposed by Radke. The capacity of the supply side and the scale of the demand side are considered in the calculations [76]. Traditional 2SFCA's treatment of distance attenuation is dichotomous (Figure 5a), which overestimates the accessibility of boundaries within a search radius. Therefore, researchers have performed various extensions based on distance decay; the essential step, however, is to add an additional distance decay function within the search radius of 2SFCA. For this study, we introduced a new distance decay function: the kernel density function. The kernel density function is a continuous concave function. The shorter the distance, the more slowly accessibility decays with distance; the greater the distance, the faster the decay (Figure 5b). We used supply–demand-based kernel density 2SFCA (SD-KD2SFCA) to measure park accessibility based on the following steps:

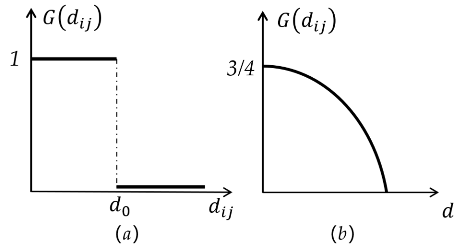


**Figure 5.** Attenuation function of 2SFCA (**a**) and kernel density 2SFCA (**b**).

Step 1: Generating the supply-to-demand ratio:

$$P_j = \frac{S_j}{\sum_{i\in\{d_{ij}\le d_0\}}^{k} D_i \times \text{Kernel Density}(d_{ij})}, \quad (1)$$

where $P_j$ is the supply-to-demand ratio in parks, indicating the per capita park area (per $m^2$); $S_j$ is the service capacity of supply point j, expressed by the park area; $D_i$ is the scale of demand point i, expressed by the community population; k is the number of space units within the threshold distance; and $KD(d_{ij})$ is the distance decay function. The function in Formula (1) is as follows:

$$\text{Kernel Density}(d_{ij}) = \begin{cases} \frac{3}{4}\left[1-\left(\frac{d_{ij}}{d_0}\right)\right]^2, & d_{ij} \le d_0 \\ 0, & d_{ij} > d_0 \end{cases}, \quad (2)$$

where $d_{ij}$ is the actual distance between i and j; $d_0$ is the threshold distance. Previous research showed that most residents prefer to walk to the surrounding parks and are usually willing to spend less than 30 min walking to parks for recreational activities [17,22]. According to the "Road Traffic Safety Law of the People's Republic of China (2021)", normal adults' walking speeds range from 1.0 m/s to 1.5 m/s, and the 30 min walking distance is about 2250 m [27]. Therefore, 2250 m was taken as the value of the threshold distance $d_0$ in this study.

Step 2: Calculating accessibility:

$$A_i^F = \sum_{j\in\{d_{ij}\le d_0\}}^{N} P_j \times \text{Kernel Density}(d_{ij}), \quad (3)$$

where $A_i^F$ is accessibility, N is the number of parks that fall into the catchment area, and $P_j$ is the supply–demand ratio calculated in the first step.

#### 4.1.2. Diversity (Di)

Diversity refers to the options available to residents in using parks. Diversity is measured by the quantity diversity ($Qd_i$) and type diversity ($Td_i$) of all parks within a threshold distance $d_0$. Similar to accessibility, we used the community centroids as the origins, and based on network analysis, we counted the quantities and types of all parks within threshold distance $d_0$ and aggregated them at the community level. All parks within $d_0$ were considered to have the same possibility of being accessed. Since the dimensions of quantity diversity and type diversity are not the same, we normalized them and used the average value as the measure of diversity. Its calculation includes the following steps:

Step 1: Counting the $Nd_i$ and $Td_i$ separately:

$$Qd_i = \sum\nolimits_{n\in[1,N]}^{N} d_n,\ d_{n=}\begin{cases}1,\ d_{ij} \le d_0\\ 0,\ d_{ij} > d_0\end{cases}, \tag{4}$$

where N is the total number of all parks, $d_{ij}$ is the actual distance between i and j, and $d_0$ is the threshold distance (2250 m).

$$Td_i = \sum\nolimits_{m\in\{d_{ij}\le d_0\}}^{M} T_m,\ T_m = \begin{cases}1,\ T_m \ne T_{m-1}\\ 0,\ T_m = T_{m-1}\end{cases}, \tag{5}$$

where M is the total number of park types within the threshold distance $d_0$ and $T_m \ne T_{m-1}$ means the same type is not counted repeatedly.

Step 2: Normalizing $Nd_i$ and $Td_i$ separately:

$$X_{nor} = \frac{X_n - X_{min}}{X_{max} - X_{min}} \tag{6}$$

where $X_{nor}$ is the normalized value, $X_n$ represents the actual value of the nth value in a set of data, and $X_{min}$ and $X_{max}$ are the minimum and maximum values, respectively.

Step 3: Calculating diversity:

$$D_i = \frac{1}{2}\left(Qd_{i(nor)} + Td_{i(nor)}\right) \tag{7}$$

where $D_i$ is the diversity index; and $Qd_{i(nor)}$ and $Td_{i(nor)}$ are the normalized quantity diversity index and type diversity index, respectively.

#### 4.1.3. Convenience (Ci)

Convenience refers to the degree of convenience for residents to enter a park. The further one is from the nearest park, the more difficult it will be to enter a park for recreational activities. Communities that are far from the nearest park have difficulty accessing any urban parks. Therefore, the distance to the nearest park is equivalent to the threshold for one community to enter parks, which determines whether community residents can enjoy park benefits in minimal time cost. In this research, we used the nearest network distance for residents to enter parks as a measure of convenience, regardless of other park attributes. Since greater distances indicate less convenience for entering parks, we used the inverse of the distance as the value for convenience. Its expression is

$$C_i = \frac{1}{d_{nearest}}, d_{nearest} = \min d_{ij}, \tag{8}$$

where $d_{ij}$ is the actual distance between i and j and $d_{nearest}$ is the distance from the community to the nearest park.

#### 4.1.4. Satisfaction (Si)

Satisfaction refers to residents' evaluation of the service quality of parks around their communities. The collection of interview questionnaires was completed in January 2020 by 13 graduate students. In addition to collecting the basic information of respondents, the questionnaire asked respondents to rate parks' perceived accessibility, landscape and environment, recreation facilities, and safety measures, and each aspect was scored on a scale of 0–10 [77,78]. The core questions of the interview questionnaire are shown in Table 3. Graduate students were responsible for interpreting the interview questions and recording the results. We ensured that at least 2 or more interview questionnaires were collected in each community and finally obtained 672 valid questionnaires. Table 4 summarizes the sociodemographic information of the all respondents.

**Table 3.** Core questions of the interview questionnaire.

| Review Aspect | Specific Question | Score |
|---|---|---|
| Perceived accessibility | Are nearby parks easily accessible in your community? | 0–10 |
| Landscape and environment | How do you feel about the landscape and environmental level of the parks around your community? | 0–10 |
| Recreational facilities | Are the recreational facilities provided by parks around your community highly standardized? | 0–10 |
| Safety measures | Do parks around your community have some effective conservation measures in place? | 0–10 |

**Table 4.** Statistics on the socio-demographic characteristics of the respondents.

| Sociodemographic Characteristics | | Percentage | Sociodemographic Characteristics | | Percentage |
|---|---|---|---|---|---|
| Gender | Male | 47.17% | Profession | Government/Public Institution Workers | 4.32% |
| | Female | 52.83% | | Teachers | 2.53% |
| Age | 24 and under | 12.80% | | Researchers | 0.45% |
| | 25–34 | 18.30% | | Students | 8.33% |
| | 35–44 | 19.05% | | Soldiers | 0.45% |
| | 45–54 | 21.13% | | Local company employees | 11.76% |
| | 55–64 | 15.33% | | Foreign company employees | 0.60% |
| | 65 and above | 13.39% | | Individual industrial and commercial households | 11.01% |
| Educational level | Junior high school and below | 35.42% | | Farmers | 4.91% |
| | High School/Secondary School | 33.33% | | Workmen | 5.65% |
| | College | 18.01% | | Retirees | 20.54% |
| | Undergraduate | 11.61% | | Freelancers | 18.60% |
| | Master and above | 1.64% | | Others | 10.86% |

The satisfaction index was calculated by weighting the scores of the four evaluation variables: perceived accessibility, landscape and environment, recreational facilities, and safety facilities. Its expression is

$$S_i = w_1 Q_1 + w_2 Q_2 + \cdots\cdots w_n Q_n, \quad (9)$$

$$w_1 = w_2 = \cdots\cdots w_n = \frac{1}{n}, \quad (10)$$

where n is the total number of review aspects, Q is a resident's score of an aspect, and w is the weight of each reviewed aspect. In this study, equal weights were used.

### 4.2. Spatial Overlap Analysis

Since the four dimensions have different practical meanings, the results of the calculations varied considerably. To avoid large biases in the measurement owing to a too-large or too-small index in a dimension, we conducted spatial overlap analysis by assigning values. The average value provided a good indication in a given dimension. Thus, we used the average value as a threshold for overlaying [22]. Its expression is

$$h_{ave} = \sum_{m\in[1,M]}^{M} h_m,\ H_{s(dim)} = \begin{cases} 1, & H_{s(dim)} \geq h_{ave} \\ 0, & H_{s(dim)} < h_{ave} \end{cases}, \tag{11}$$

$$H_{sum} = H_1 + H_2 \ldots\ldots + H_{s(dim)}, \tag{12}$$

where M is the number of space units, representing 175 communities to be measured; $h_{ave}$ is the mean value of the park access index of all communities; and $H_{s(dim)}$ is the park access index of a community. Taking a community as an example, if its $H_{s(dim)} \geq h_{ave}$, it is assigned 1; otherwise, it is assigned 0. $H_{sum}$ is the $H_{s(dim)}$ of all dimensions summed. The higher the value, the higher the comprehensive level of park access enjoyed by the community and vice versa. If $H_{sum}$ = 0, the community hardly has any park access.

### 4.3. Lorenz Curve and Gini Coefficient

The Lorenz curve and Gini coefficient (GC) are the earliest indicators used to judge equity in income distribution. Parks are unequally distributed in cities, which has connotations similar to income distribution. Thus, we considered the Lorenz curve and GC suitable for describing how well the park access index matched the population. The expression is

$$GC = \left| \sum_{i=1}^{M} [(O_{i-1} - O_i)T_i] - 1 \right|, \tag{13}$$

where M is the number of space units, O is the cumulative value of the park access index, and $T_i$ is the ratio of the population of a certain space unit to the total population. GC is in the range $[0, 1]$. The closer to 0, the more even the distribution; the further from 0, the more unequal the distribution. The GC of the park access index and population matching was divided into five grades [79], as shown in Table 5.

**Table 5.** Thresholds of the Gini coefficient.

| Scope | Rank |
|---|---|
| [0, 0.2] | Exact match |
| [0.2, 0.3] | Relative match |
| [0.3, 0.4] | Relatively reasonable match |
| [0.4, 0.5] | Relative mismatch |
| [0.5, 1] | Total mismatch |

## 5. Results

### 5.1. Spatial Equity in Parks

#### 5.1.1. Distribution of the Four Dimensions

As shown in Figure 6, for *Ai*, Yinxiang community had the highest per capita reachable area of parks among all the communities of 707.0594 $m^2$. Meanwhile, 18 communities had almost no reachable area within the threshold distance $d_0$ (2250 m); for *Di*, those 18 communities also had almost no choices. In contrast, the Siwangting community, which had 46 parks and five park types within 2250 m, had great autonomy. The Jiulong Garden community had the best performance in terms of *Ci*—about 30 m from the nearest park entrance. However, the distance between Hangji Village and the nearest park entrance exceeded 6000 m; thus, it was more difficult to enter a park. For *Si*, we used a questionnaire to allow community residents to evaluate park service quality. Given the limited number of valid questionnaires collected, residents' evaluations of park service quality varied widely. The Wenchang community's *Si* was the highest, at 9.5, but residents of the Shabei Community believed that they did not have good park service quality (*Si* of 2.8). Table 6 shows the descriptive statistics of the measurement results for the four dimensions.

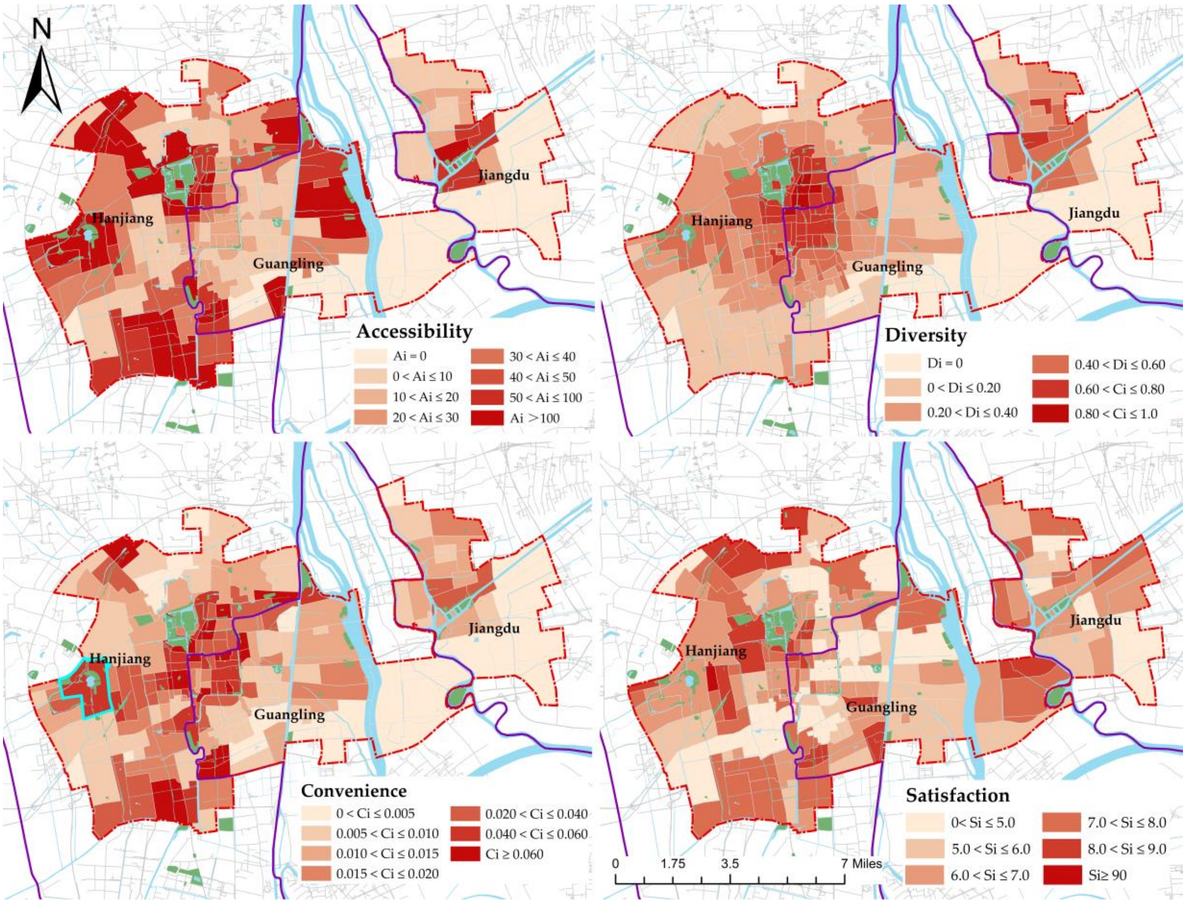


**Figure 6.** Measurement results for the four dimensions.

**Table 6.** Descriptive statistics of the measurement results for the four dimensions.

| Dimension | N | Minimum | Maximum | Average | Standard Deviation |
|---|---|---|---|---|---|
| Accessibility (*Ai*) | 175 | 0 | 707.0594 | 50.9915 | 100.3525 |
| Diversity (*Di*) | 175 | 0 | 0.9694 | 1.94 | 0.2430 |
| Convenience (*Ci*) | 175 | 0.000154 | 0.031611 | 0.002827 | 0.004618 |
| Satisfaction (*Si*) | 175 | 2.8 | 9.5 | 6.1750 | 1.4216 |

### 5.1.2. Distribution of the Comprehensive Level

Using spatial overlap analysis, we identified areas that were overserved and underserved by park access in Yangzhou's built-up districts (Figure 7). Overall, the comprehensive level of the four dimensions was the highest in the east and the lowest in the west, with a general downward trend from the city center (Wenchang Pavilion) to the suburbs. Additionally, communities near large parks and park agglomerations were found to have higher levels of park access. According to our statistics based on the population and area of communities (Table 7), 31 communities had almost no park access, accounting for 25.31% and 16.84% of the total area and population of all communities, respectively. We observed that 103 communities had low or relatively low levels of park access, accounting for 54.56%

and 60.01% of the total area and population of all communities, respectively. There were 41 communities with high and relatively high levels of park access, accounting for 20.71% and 22.56% of the total area and population of all communities, respectively.

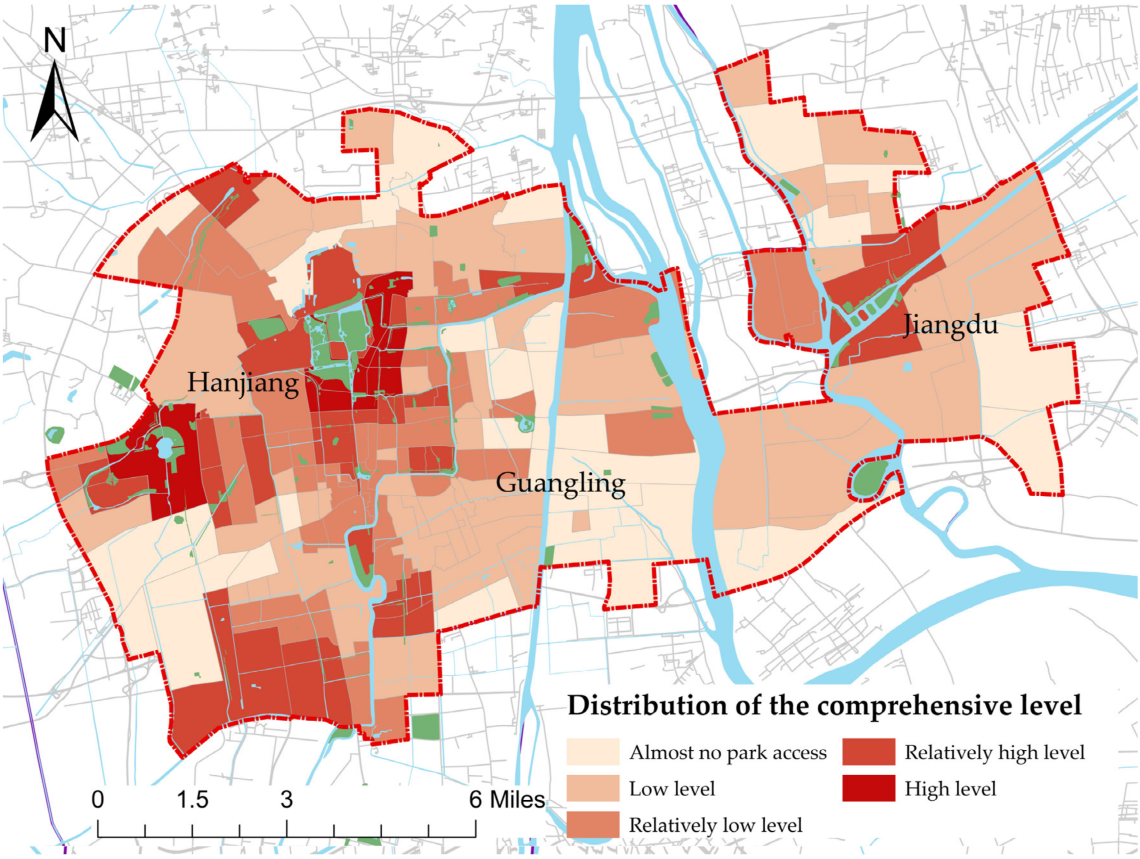


**Figure 7.** Distribution of the comprehensive level.

**Table 7.** Descriptive statistics of the comprehensive level.

| Rank | N | Accounting for Total Number of Communities | Accounting for Community Area | Accounting for the Population |
|---|---|---|---|---|
| Almost no park access | 31 | 17.72% | 25.31% | 16.84% |
| low level | 59 | 33.71% | 37.64% | 32.99% |
| Relatively low level | 44 | 25.14% | 16.92% | 27.02% |
| Relatively high level | 33 | 18.86% | 15.90% | 18.33% |
| High level | 8 | 4.57% | 4.81% | 4.23% |

5.1.3. Equity in the Spatial Distribution of Parks

The Lorenz curve in this study was composed of the cumulative percentage of the four dimensions and the cumulative percentage of the community population. The greater the arc of the curve, the more inequitable the dimension (Figure 8). We found that *Ai* was the least equitable and that *Ci* was second only to *Ai*. The best equity performance was observed for *Ci*, which was closest to perfect equity. We further calculated the GC (Table 8). Referring to the intrinsic grading of the GC, we found that only *Ci* and population distribution were reasonably matched, *Di* was relatively mismatched with population distribution, and *Ai* and *Ci* were not matched at all.

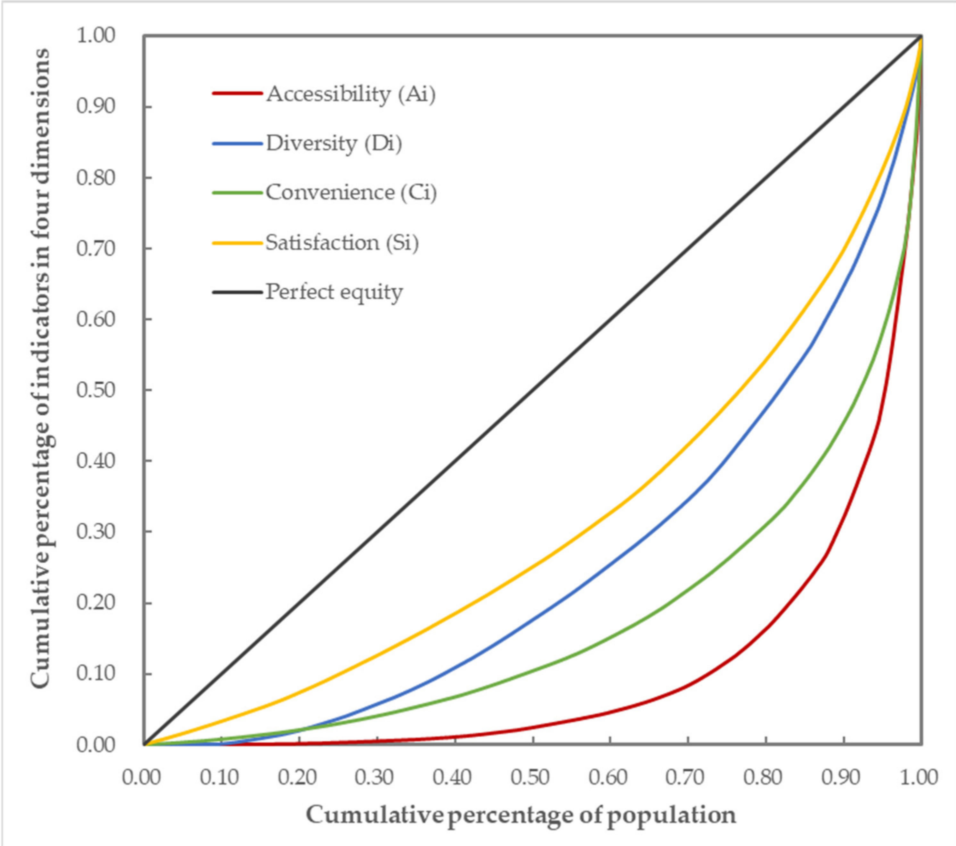


**Figure 8.** Lorenz curve of the four dimensions.

**Table 8.** Gini coefficient of the four dimensions.

| Dimension | Accessibility (*Ai*) | Diversity (*Di*) | Convenience (*Ci*) | Satisfaction (*Si*) |
|---|---|---|---|---|
| GC | 0.7979 | 0.4946 | 0.6511 | 0.3766 |
| Rank | Total mismatch | Relative mismatch | Total mismatch | Relatively reasonable match |

## *5.2. Social Equity in Parks*

### 5.2.1. Equity Based on Community Properties

Different community properties can often reflect socioeconomic differences. We selected seven variables from four properties—population, location, housing, and facilities—and analyzed whether park equity under different dimensions was associated with community properties. We calculated Spearman's rank correlation coefficient and Kendall's rank correlation coefficient for the two types of variables separately in SPSS 22.0. Table 9 shows the results. *Ai* was positively correlated with X4 and X5. It had the strongest correlation with X4, but the correlation with other community properties was not significant. The correlation between *Di* and the seven variables was significant at the 0.01 level. It was positively correlated with X1, X4, X5, X6, and X7 and negatively correlated with X2 and X3, among which the strongest correlation was with X4. The correlation between *Ci* and the seven variables was also significant at a confidence level of 0.01. The forward or reverse relationship with property variables was basically the same as for *Di*, and X5 had the strongest correlation. *Si* was significantly affected by residents' subjective feelings, and the correlation with property variables was generally lower than for other dimensions. Spearman's correlation coefficient showed that *Si* was positively correlated with X4 at a confidence level of 0.05 and negatively correlated with X1 at a confidence level of 0.01. The

Kendall correlation coefficient showed that *Si* was correlated with both at a confidence level of 0.05. We can conclude, then, that communities with lower building floors, higher housing prices, more convenient amenities, and closer proximity to the city center tended to have better park access.

**Table 9.** Correlations between the four dimensions and community properties.

| Dimension | N | Analysis Method | X1 | X2 | X3 | X4 | X5 | X6 | X7 |
|---|---|---|---|---|---|---|---|---|---|
| Accessibility (*Ai*) | 175 | Spearman's rank correlation | −0.092 | −0.115 | 0.022 | 0.249 ** | 0.151 * | 0.040 | −0.051 |
| | 175 | Kendall rank correlation | −0.077 | −0.083 | 0.010 | 0.167 ** | 0.103 * | 0.018 | −0.040 |
| Diversity (*Di*) | 175 | Spearman's rank correlation | 0.593 ** | −0.681 ** | −0.494 ** | 0.697 ** | 0.550 ** | 0.550 ** | 0.301 ** |
| | 175 | Kendall rank correlation | 0.416 ** | −0.510 ** | −0.345 ** | 0.300 ** | 0.522 ** | 0.392 ** | 0.436 ** |
| Convenience (*Ci*) | 175 | Spearman's rank correlation | 0.216 ** | −0.361 ** | −0.285 ** | 0.370 ** | 0.457 ** | 0.322 ** | 0.284 ** |
| | 175 | Kendall rank correlation | 0.152 ** | −0.267 ** | −0.206 ** | 0.270 ** | 0.343 ** | 0.240 ** | 0.207 ** |
| Satisfaction (*Si*) | 175 | Spearman's rank correlation | −0.163 ** | 0.053 | 0.048 | 0.158 * | 0.061 | −0.008 | −0.027 |
| | 175 | Kendall rank correlation | −0.110 * | 0.032 | 0.032 | 0.113 * | 0.041 | −0.003 | −0.016 |

Note: ** significant at the 0.01 level (two-tailed); * significant at the 0.05 level (two-tailed).

#### 5.2.2. Equity Based on Income Level

Since China's "reform and opening up", residents' living standards have significantly improved. However, income disparities between different groups are still large, and acquiring housing through the market is highly dependent on disposable income. It is reasonable, then, to distinguish the income levels of communities based on housing prices [17]. To make the differences even more significant, we divided income groups into three categories according to community real estate prices: the top 20%, middle 60%, and bottom 20% were high, middle, and low income, respectively [17]. The comprehensive distribution of parks was inequitable across income groups (Table 10). High-income communities had more park access than middle- and low-income communities combined. Only 11.43% of high-income communities had no park access, whereas this percentage was 28.57% in low-income communities. In addition, 45.72% of the high-income communities had high or relatively high levels of park access compared to 17.15% and 20% of the low- and middle-income groups, respectively.

**Table 10.** Comprehensive level of park access among different income groups.

| Income Group | High Level | Relatively High Level | Relatively Low Level | Low Level | No Access |
|---|---|---|---|---|---|
| High-income group | 14.29% | 31.43% | 31.43% | 11.43% | 11.43% |
| Middle-income group | 2.86% | 14.29% | 28.57% | 38.10% | 16.69% |
| Low-income group | 0% | 20.00% | 8.57% | 42.86% | 28.57% |

## 6. Discussion

### *6.1. Theoretical and Methodological Contributions*

Parks and UGSs provide various benefits for humans, including regarding physical and mental well-being [3]. Therefore, the equitable distribution of parks is relevant to the health and well-being of all urban residents. In the past, park equity was estimated based on park size, number, and distance, but those variables do not reflect the actual use of parks [80,81]. With the development of GIS, accessibility has been widely used to study park equity. However, the factors affecting park users should be holistically considered, and park equity should be measured across multiple dimensions beyond space-based accessibility [22,23]. In this study, we therefore developed a new framework for evaluating park equity by integrating the four dimensions of accessibility, diversity, satisfaction, and convenience. From the perspective of sociospatial dialectics, parks have both spatial and social properties [66,82]. However, the authors of previous studies have mostly considered spatiality and have not given enough consideration to the social aspects of parks. Most researchers tend to measure the equity of park distribution in two-dimensional space without considering the relationship between socioeconomic differences and park access, thus ignoring the differences in park allocation among different groups. In this study, we therefore integrated the spatial and social equity of parks as a whole and developed a multidimensional framework to evaluate park equity.

Our study offers a more convenient, feasible, and replicable framework for measuring park equity through a combination of traditional data and big data. Big data have been used for a wide range of studies in China, so they are more accurate than traditional data, as well as being easy and inexpensive to access. Moreover, in this study, we proposed models and methods for measuring spatial and social equity. For example, SD-KD2SFCA was used for the first time to measure park accessibility, and models such as correlation coefficients, linear regression, and geographically weighted regression were all shown to be good fits for the relationship between park indices and factors such as population and environment. The use of these models could help researchers measure park equity among different social groups.

### *6.2. Implications for Urban Park Planning and Management*

These findings have important implications for promoting park equity in Yangzhou's built-up districts. Various policies and proposals for urban park planning could help mitigate such inequities. On the one hand, more attention should be paid to the weak dimensions of park access, especially communities with below-average levels in all four dimensions. To alleviate residents' needs for parks to a certain extent, the government can consider adding some small green spaces, such as pocket parks and community parks, to the sporadic plots near blocks and transportation stations [22]. Park convenience is regarded as the threshold for a community to enter parks. Since Hanji Village is more than 6000 m away from the nearest park, it is difficult for its residents to enter any park in the city, requiring a high time cost. The government can help alleviate inequity for communities such as Hanji Village by appropriately increasing the number of parks around them or setting up dedicated bus routes to other large- and medium-sized parks. For park satisfaction, since data analysis often cannot fully reflect actual use, planners should solicit residents' suggestions when laying out urban parks. Residents' demands for parks and suggestions for improving park quality can be collected through questionnaire interviews. For example, respondents in the Shabei community complained about the lack of parks and outdated facilities. To improve park quality, they hoped that the government would build new parks and adjust the facility structures of old parks. For communities around the city center and close to large parks or park-intensive areas, accessibility and diversity are significantly better than those for communities on urban fringes. Park allocation should prioritize urban fringes and areas with lower park densities in future planning [83,84].

On the other hand, park access for vulnerable groups should be considered. Market mechanisms may aggravate inequities in the development of ecosystem services in different regions. Governments should therefore take steps to lower the threshold for park accessibility and consider providing appropriate green infrastructure for vulnerable groups to address the unbalanced development of ecosystem services caused by capital [17,60]. In this study, we found that the uneven distribution of parks is related to the socioeconomic properties of the community. Communities that were closer to the city center, those that had fewer residential floors, and those that had better facilities tended to have better park access. Additionally, high-income groups have better park access than low- and middle-income groups. Higher-income residents usually have relatively large living spaces, and some even have gardens, so their needs for public green spaces are relatively small. Public green spaces should therefore be oriented towards low-income groups when optimizing park layouts. Additionally, the government should increase the participation of different socioeconomic groups in the park planning process, thereby improving decision makers' understanding of the needs of different groups. These suggestions can help the Yangzhou Municipal Government, which aims to construct a "park city", make decisions about park planning and management and be alert to green space paradox [85].

### 6.3. Limitations and Future Research

Some limitations of this study should be acknowledged. First, accessibility was calculated using walking as the only travel mode. Other studies, researchers calculated park accessibility based on multiple travel modes (e.g., bike, bus, and car) [26,86]. Chang et al. (2019) and Li et al. (2021), for example, studied park accessibility and park equity under multiple travel modes in Hong Kong and Nanjing, China, respectively. Future research could consider calculating accessibility under multiple travel modes and thereby more comprehensively evaluate park equity. Second, in the calculation of satisfaction, the graduate students only collected 672 interview questionnaires. Although this was enough for a certain explanatory effect, more questionnaires are needed to further strengthen the reliability of our results. Third, we assumed the four dimensions had equal importance. In measuring the comprehensive level of park access, we used the mean value as the threshold and applied spatial overlap for analysis. There should be a ranking of importance among the four dimensions. Future research could apply weighted overlap to more accurately measure the comprehensive level of park access. Finally, we analyzed park equity at the community level, but more precise data, such as household-level data, are now available [17]. We also did not include other demographic stratification indicators (e.g., ethnic characteristics, age, and gender) [87,88] that might affect equity. Future studies should therefore further refine their data.

## 7. Conclusions

Evaluating park equity has become a hot topic in the field of spatial justice, and it is essential for park planning and layout. In this study, we developed a comprehensive evaluation framework for measuring park equity in four dimensions: accessibility, diversity, convenience and satisfaction. Taking Yangzhou's built-up districts as the study area, the spatial equity and social equity of the parks were measured by using traditional data and big data. The conclusions are as follows.

For park spatial equity, park allocation was not equitably represented at the community level in Yangzhou's built-up districts, as 23.43% of the communities received high- or relatively high-level park access but 17.72% received little or no park access. Additionally, we found that communities close to the city center and park-intensive areas had significantly higher levels of park access than other areas. To promoting equity in park distribution, more attention should be paid to the areas with low levels of park access. A growing body of research has acknowledged the benefits of small green spaces, which can satisfy residents' daily leisure activities while avoiding the green space paradox [85]. Because the amount of unused land in cities is limited, governments can consider adding small green spaces such as community parks and pocket parks to alleviate inequality.

Compared to traditional research on park spatial equity, we further confirmed the correlation between the socioeconomic properties and the distribution of park access. In Yangzhou's built-up districts, communities that were closer to the city center, had fewer residential floors, and had better facilities tended to have better park access. In addition, high-income groups enjoyed significantly better park access than low-income groups. Housing prices in the residential areas of vulnerable groups are relatively low, and these areas are also suitable for park distribution. Therefore, the government should prioritize residents' needs to use parks in these areas. In addition, public participation is an important part of realizing the equity of park layout, and it is necessary to strengthen the participation of different socioeconomic groups in the decision-making process of urban park planning [22]. The government should safeguard the "green rights" of vulnerable groups and be wary of "green" becoming synonymous with "money" and "power".

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