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Study on the Social Equity Impact Path of Community Life Circle Green Space from the Perspective of Configuration

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Abstract

The social equity of green space is influenced by multiple elements. This study proposed a novel model to effectively answer the effect of the complex interactions among the elements on the social equity of green spaces in community life circles. Accordingly, it selected the Shangcheng District of Hangzhou as the case study. First, it employed the Gaussian-based 2-step floating catchment area (2SFCA) method combined with the OD cost matrix to calculate the accessibility of green park space within the 15-min life circle of each community. Second, the Lorenz curve and Gini coefficient were employed to measure the social equity of green park space. Finally, the qualitative comparative analysis (QCA) deduction and inference led to the grouping path of high green space accessibility. Results demonstrate that (1) the accessibility of parks in the Shangcheng District shows a spatial layout with high values in the southwest and north and low values in the central and east, and the Gini coefficient of park accessibility distribution is 0.94, which is a serious inequity. (2) Road network density, population density, number of park entrances, park area, number of green park spaces, and park green space shape index cannot individually constitute the necessary conditions for high green space accessibility. (3) Five configurations reflect the multiple ways of achieving high green space accessibility in different areas. Policymakers can compare the cases with similar conditions among the five configurations according to the current characteristics of the regions and achieve high green space accessibility with minimum cost, thus improving overall social equity.

Keywords

Greenfield social equity; Green space accessibility; QCA; Community life circle

Introduction

The social equity of parkland is a fundamental aspect of optimizing urban public services and is related to an effective strategy of equalizing public services (Li et al., 2020). Research attention on this topic has been rapidly increasing in recent years (Li et al., 2021). In particular, the global COVID-19 has changed people's lifestyle and their way of relating, also impacting many of their everyday habits and consumption (Merchante et al., 2021). Hangzhou proposes to construct a 15-min community life circle that advocates a people-oriented approach. It starts from the daily needs of residents and taps the difference between demand and supply (Lulu & Yungang, 2017), which provides new ideas for the study of social equity in green park spaces. Accessibility is commonly used to measure the social equity of urban green spaces in the current studies (Fernández & Wu, 2016; Rigolon, 2016; Oh & Jeong, 2007; Xu et al., 2018; Nicholls, 2001). Exploring the factors of park green space accessibility and its mechanism of action has profound theoretical value for clarifying the complex causal mechanism of the social equity of green park space. It also has important practical significance for allocating and optimizing urban public green space resources (Chen, Yue & La-Rosa, 2020).

Today's research on the factors influencing the accessibility of green spaces focuses on the socio-economic factors, the characteristics of green spaces, and the impact of traffic. Jim et al. (2013) used a questionnaire to assess the influence of respondents' socio-economic status and perceptions on the accessibility of green spaces. Yin et al. (2019) employed linear regression models to analyze the changing patterns of park green space area and shape and road network density on the service area of green park space and its service efficiency. Zhang et al. (2018) explored the effects of park attributes, park location, park environment, and public transportation on park accessibility through multiple linear regressions. Shangguan et al. (2018) used SPSS fitting to analyze the effects of park green space area, population density, road density, and shape index on the accessibility of urban park green space. Liu et al. (2021) analyzed the effect of the interaction of different factors on the accessibility of green spaces using the idea of geographic probes and parameter substitution. Throughout the above studies, the existing literature is found to lack focus on the possible equivalent paths formed by different combinations of elements and cannot effectively answer the impact of complex interactions among elements on green space accessibility. Following previous studies, this study infers that a combination of multiple factors may influence green space accessibility. Thus, analyzing the synergistic effects of multiple factors on green space accessibility is deemed essential from a histological perspective.

This study introduces qualitative comparative analysis (QCA), which is widely used in management and other fields for scientific research. QCA can explore the "configuration effect" of multiple factors and reveal different paths to achieve the same output (Kallmuenzer et al., 2021). The purpose of the introduction of QCA is to use the optimized analysis tools and methods to study and discuss existing practical problems from a new perspective （Gołębiowski, Żak & Kisielewski, 2020). This study selects community green spaces in the Shangcheng District of Hangzhou, Zhejiang Province, China, as the research object. 2SFCA method combined with OD cost matrix is employed to calculate the accessibility of green park spaces within the 15-min life circle of each community from the perspective of the green space supply-demand ratio. Then, the Gini coefficient by the Lorenz curve is calculated to measure the social equity of green park spaces in the whole Shangcheng District. Finally, the QCA deduction and inference lead to the configuration path of high green space accessibility and exploration of the complex causal mechanism of multiple factors concurrently affecting the accessibility of green park spaces. It provides a reference for coordinating the supply-demand problem between green spaces and residents and optimizing the layout of green park spaces.

State of the art

Urban green space is an important carrier of urban public services, and it has a long research history regarding its equity. At present, scholars have conducted many studies on multiple dimensions of green space equity, which are more detailed and refined in terms of scale and scope, and the research content has certain diversity. Yin et al. (2006) analyzed the spatial and temporal dynamics between the overall green space system and the accessibility of parks and squares in Jinan City and their reasons by using the cost-weighted distance method and combining the concepts and principles of landscape accessibility. However, the study could obtain a more accurate accessibility analysis if factors such as the spatial distribution characteristics of the population and the fatigue level of the human movement were incorporated into the accessibility analysis. Lu et al. (2016) used buffer zone analysis and network analysis to compare and analyze the accessibility of green park spaces within the Third Ring Road in Shenyang and found that the road network form and road network density are important factors affecting the accessibility of green spaces. In addition, park shape, park area, and surrounding population density also deserve further research. Yin et al. (2006) conducted a stepwise regression analysis and built a linear regression model, and found that green space area is the most important influencing factor of green space accessibility.However, the mechanism of multi-factor interaction influence has not been studied by relevant models. Shangguan et al. (2018) selected four factors: park green space area, population density, road density, and shape index, and used SPSS to conduct a correlation analysis of urban park green space accessibility. In the later stage, we still need to find a balance in the issues of park area size, shape scale, and layout site selection. Liu et al. (2021) employed the idea of geographic probe and parameter substitution to explore the influencing factors of green space accessibility and found that the interaction of different factors has stronger explanatory power on green space accessibility, and the spatial linear distance and road network density are the key factors of accessibility change. Xu et al. (2021) conducted the equity analysis from three dimensions of urban park green space quantity, quality, and accessibility. They concluded that all three were significantly related to equity. However, the perspective selection was broader, and future studies can analyze equity from a more detailed green space perspective. Kuang, Li & Zhou (2022) effectively analyzed the spatial equity differences in the distribution of green spaces in urban parks and derived an evaluation method for specific equity. The study lacks a survey of green spaces below 1 km^2, and a sample type is somewhat lacking. Wendel, Downs & Mihelcic (2015) found no differences in the overall accessibility between Tampa and East Tampa. However, inequalities were more significant when considering green spaces' quality, diversity, and size. Wolch, Byrne & Newell (2014) analyzed the "green space paradox" from the perspective of park availability in terms of equity. They used the "just enough green" strategy to ensure that the internal facilities of green spaces are adapted to the economic level of the surrounding community, thus effectively ensuring the equity of green spaces. Hashem (2015) analyzed the park provision rate data in terms of population size, availability of green space, and green space to building area ratio to analyze the equity, which has a high degree of scientific accuracy but lacks spatial accessibility analysis. Thus, the study has some defects. Lara-Valencia & García-Pérez (2013) conducted an equity analysis regarding the number of green spaces, geographic location, and internal facilities. They concluded that all three produce a relationship with equity and that green space equity also correlates with socio-economic status and race. Mears et al. (2019) conducted systematic equity studies on public green spaces, health-promoting green spaces, child-serving green spaces, and social dimensions, concluding that the economic level and age class influence green space equity. However, research scarcely considers equity from factors within green spaces. Nghiem et al. (2021) concluded that an equitable distribution of green and blue spaces could be achieved in compact cities by analyzing multiple spatial scales. Environmental equity is detectable at large scales but not at small scales. Song et al. (2021) quantified the population size of cities through comparative studies. They found that green space equity strongly correlates with time variation and urban characteristics. However, the study suffers from a lack of equity exploration with green space quality as content and a lack of relevant studies involving green space exposure. Edwards & Larson (2022) examined the equity of protected areas from a social interaction perspective, using accessibility as a judgment basis, and concluded that different stakeholders' perspectives on demand for green space affect the equity of green space access. The study suggested that future research could explore the equity of green space from the nature of recreation.

A review of the above studies reveals that the factors influencing the accessibility of green spaces are mostly centered on the characteristics of the green space itself, traffic conditions, and demographic characteristics. The following aspects are still lacking in the research methodology. (1) The existing literature does not address the possible equivalent paths formed by different combinations of factors, which cannot effectively answer the impact of complex interactions among factors on green space accessibility. By contrast, the complexity of green space accessibility is influenced by multiple factors, and different combinations of factors may produce the same results, i.e., multiple equivalent paths may exist. Revealing the complex causes of high green space accessibility is difficult when using the traditional quantitative research method with the net effect as the primary research perspective. Analyzing the synergistic effects of multiple factors on green space accessibility is necessary from a holistic perspective. (2) In terms of research methodology, most current research focuses on mathematical and statistical models based on the principle of "linear regression," which somewhat restricts researchers' thinking about problem-solving and requires the introduction of new methodologies to enrich the spectrum of research methods. This study adopts the QCA, which is widely used in sociology and considers the complex linkage effects among the influencing factors to analyze the influence path of social equity from a holistic perspective.

The remainder of this study is organized as follows. Section 3 analyzes the current situation of the research object, explains the source of research data, and constructs a research model for the evaluation of social equity of urban park green space and its influence path. The fourth section uses the 2SFCA method combined with the OD cost matrix to calculate park green space accessibility and then calculates the degree of the social equity of green park space through the Lorenz curve. Finally, the configuration paths are obtained through QCA analysis. The last section summarizes the study and provides relevant conclusions from both theoretical and practical perspectives.

Methodology

This study incorporates research methods from economics and sociology on the basis of the discipline of landscape architecture. It then established the research model for evaluating the social equity of urban park green spaces and their impact paths from the integration of all disciplines. It initially takes the communities in the Shangcheng District as the division object, from which 621 residential areas are divided as points of need, and the resident population of residential areas is estimated according to the proportion of the residential area to the total residential area of the community. The specific entrance and exit locations of the dark green areas in the study area are extracted as supply points. Second, the walking speed is set to 1 m/s, and the OD cost matrix is established on the basis of the road network to calculate the minimum time for each residential area to reach the green park space. Again, the 2SFCA method is applied to calculate the park green space accessibility within the 15-min life circle of each residential area. The park green space accessibility of each community is summarized, and then the Lorenz curve and Gini coefficient are employed to evaluate the degree of the social equity of green park space in the Shangcheng District as a whole. Finally, QCA analysis is conducted with the community-level park green space accessibility as the outcome condition; and the road network density, population density, number of park entrances, park area, number of green park spaces, and park green space shape index as the causal condition to explore the cause configuration that affects the social equity of green park space.

Research Methods

The green space accessibility evaluation using the 2SFCA method is divided into two steps. The supply-to-demand ratio R_j is found in the first step for each green space supply point *j*.

$$R_j = \frac{S_j}{\sum k \in \{d_k \leq d_0\} G\left(d_{kj}, d_0\right) P_k} \tag{1}$$

where S_j is the area of green space supply point *j*; d_0 is the given spatial distance threshold; d_{kj} is the spatial distance from the geometric center of settlement *k* to green space supply point *j*. For parks with multiple entrances, the distance of the road network from settlement *k* to the nearest entrance is selected; P_j is the number of permanent residents in settlement *k*; *G* (d_{kj}, d_0) is the Gaussian decay function, which is calculated as shown in Equation (2).

$$G(d_{kj}, d_0) = \begin{cases} \dfrac{e^{-\left(\frac{1}{2}\right)\times\left(\frac{d_{kj}}{d_0}\right)^2} - e^{-\left(\frac{1}{2}\right)}}{1 - e^{-\left(\frac{1}{2}\right)}}, d_{kj} \leq d_0 \\ 0, d_{kj} \geq d_0 \end{cases} \tag{2}$$

In the second step, the green space accessibility A_i is calculated for each residential area *i*.

$$A_i = \sum l \in \{d_{il} < d_0\} G(d_{il}, d_0)\, R_l \tag{3}$$

where R_l denotes the ratio of supply to demand of green space *l* in the spatial action domain（$d_{il} \leq d_0$）of the residential area *i*. Other indicators are the same as Equation (1).

The traditional Gaussian two-step moving search method ignores the influence of the virtual traffic network. This study calculates the road network travel time t from each residential area to the nearest entrance of the green park space using the OD cost matrix. The time cost t is used instead of the Euclidean distance cost *d*. t_0 is set to 15 min, which better reflects the actual connotation of accessibility (Wang & Wang, 2018). The improved evaluation model is

$$A_i = \sum l \in \{t \leq t_0\} G(t_{il}, t_0) \frac{S_j}{\sum k \in \left\{t_{kj} \leq t_0\right\} G(t_{kj}, t_0) P_k} \tag{4}$$

This study defines the Lorenz curve as a function between the cumulative proportion of the resident population in each community in the study area and the cumulative proportion of green space accessibility in each community. The Gini coefficient was calculated on the basis of the Lorenz curve with a value between 0 and 1, and Table 1 shows the corresponding social equity levels (Schneider, 2021).

Tab. 1. Gini coefficient classification table

Value of Gini coefficient	＜0.2	0.2-0.3	0.3-0.4	0.4-0.5	＞0.5
Social fairness level	Too average	More than average	More reasonable	The gap is too large	Disparity is large

QCA adopts a holistic and systematic approach to analysis, considering the influence of multiple causal conditions constituting a configuration rather than individual factors on the results (Kallmuenzer et al., 2021). Considering that this study's causal and outcome conditions are continuous variables, it chose the Fuzzy-set Qualitative Comparative Analysis (fsQCA) that allows partial affiliation. The theoretical basis of the high green space accessibility impact path and the QCA model are as follows:

The factors influencing the accessibility of parkland are typically divided into three aspects, namely, the supply-side parkland, the demand-side residents, and the nexus transportation conditions linking the two (Dony, Delmelle & Delmelle, 2015). The influence of the park green space's factors on accessibility is reflected in the park's attractiveness, the number of green park spaces, the number of park entrances and exits, and the park green space shape index (Shukla & Jain, 2021; Xiao et al., 2017). Previous studies have shown that the larger the scale of green space, the more complete its internal service facilities will be and the more vigorous its attractiveness to people (Baur & Tynon, 2010). Accordingly, this study chose to use park green space area as a proxy for green space attractiveness. Second, the superiority or inferiority of traffic conditions determines residents' ease of reaching green park areas (Xiao et al., 2018). This study takes road network density as a quantitative expression of traffic conditions. Analyzed from the perspective of demand-side residents, residents are the endpoint of the park green space accessibility influence model. Within a specific geographical area, population density directly affects the probability of walking trips and indirectly affects the frequency of reaching public facilities (Agrawal & Schimek, 2007). Population density is closely related to regional green space accessibility (Zhou et al., 2016), thus proving the necessity of including residents in the accessibility analysis factors. In summary, this study explores the complex causal mechanism of the three aspects, namely, green space own factors, population distribution, and traffic conditions, affecting the accessibility of green park space from the perspectives of supply and demand. Figure 1 illustrates the theoretical model.

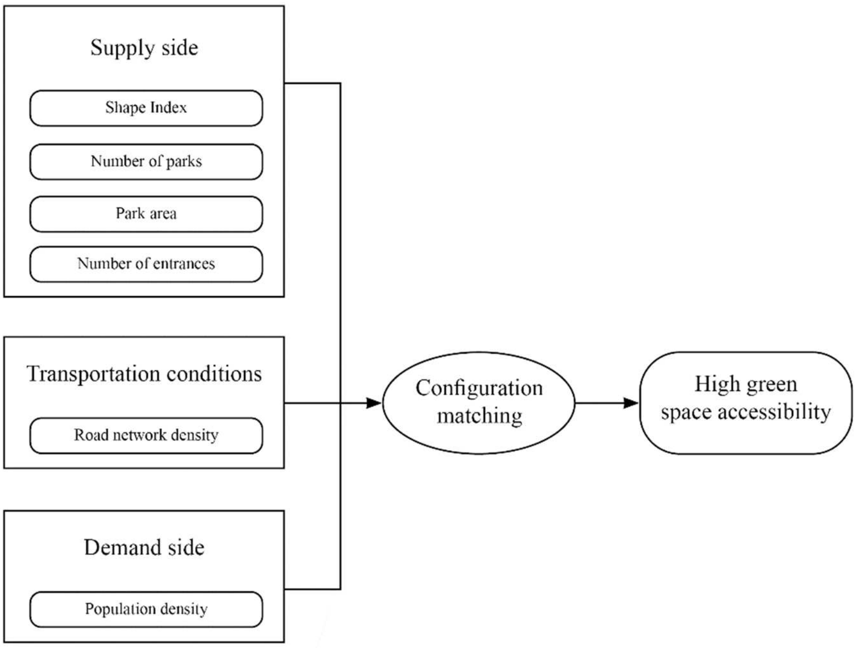

Fig. 1. Influencing mechanism model of high green space accessibility

Research Objects

Shangcheng District of Hangzhou, located in the middle of China's mainland, is the object of this study. It is with 119.75 km^2, 14 streets, 199 communities, and a resident population of 1,323,467 in the seventh National Census (China's national population census in 2020). The green areas in this study represent the green park areas open to the public for free. Considering that the green park areas around the administrative boundary of the Shangcheng District also provide recreation to the residents of the Shangcheng District, the green park areas within the Shangcheng District and its 1,000 m buffer zone are included in the collection scope of this study. Among them, the complete area of the park green space that falls within this buffer zone was chosen to be included in the study for some areas.

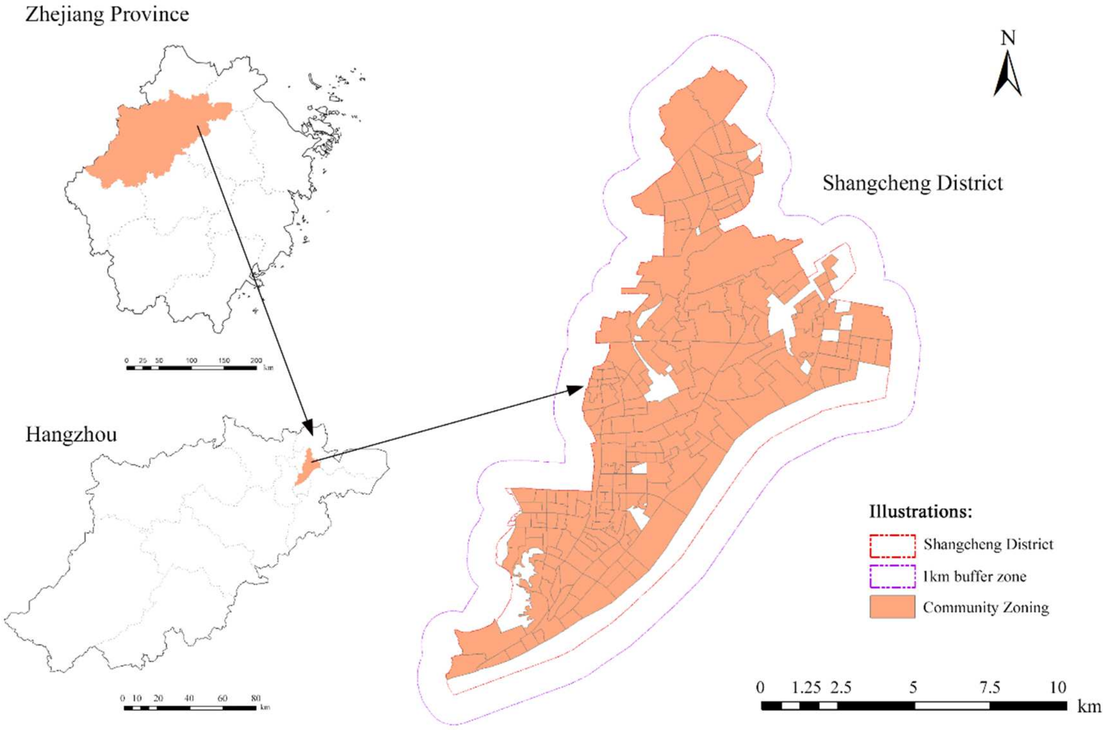

Fig. 2. Location map of Shangcheng District, Hangzhou

Data sources

The visual interpretation of Google remote sensing image data with a resolution of 2m downloaded from LocalSpace was used as the primary data, supplemented by the correction of Baidu Map and Amap, to extract thematic information such as green park areas and park entrances and exits. Subsequently, a total of 113 green park areas were extracted. The administrative zoning data come from the Zhejiang Province Geographic Information Public Service Platform. Community-level population data were obtained from the Zhejiang Government Services Network and official public numbers of communities, to name a few. Among them, the Kaihua community, Kakeqiao community, Wangjiajing community, and Xiangjiang community were excluded due to missing data, and a total of 195 communities were involved in the evaluation. Road data were obtained from OpenStreetMap, Amap, and Baidu Map, among others. All spatial data were aligned using the unified spatial coordinate system WGS 1984 UTM Zone 51N to ensure that all data were compatible. Figure 3 shows the population data and green space distribution of each community in the study area.

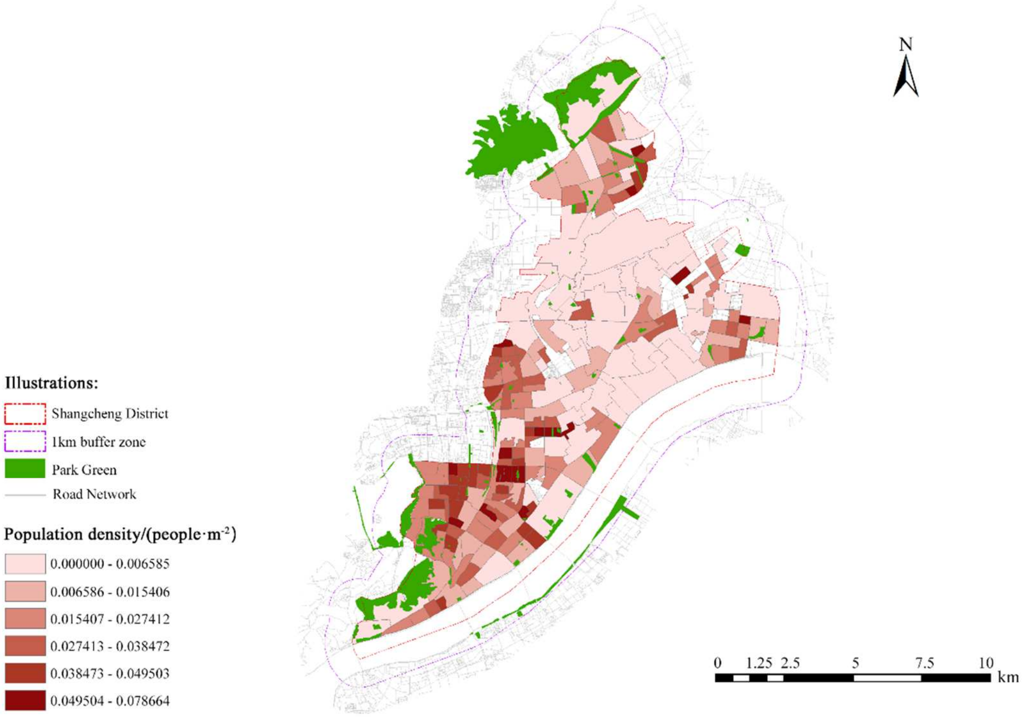

Fig. 3. Community-level population density and green space distribution in Shangcheng

Result Analysis and Discussion

Reachability results

Figure 4 shows the OD cost matrix after filtering according to the threshold of a 15-min walk, and the accessibility of green park space in the Shangcheng District is obtained by using the 2SFCA method on this basis, as shown in Figures 5 and 6. In general, the accessibility of green park space demonstrates a spatial layout with the communities around Phoenix Mountain Scenic Area, Wushan Scenic Area, West Lake Scenic Area, and Gaoting Mountain Scenic Area in the southwestern part of the Shangcheng District as high-value areas and the central and eastern parts of the Shangcheng District as low-value areas. The high accessibility area includes 16 communities around Phoenix Mountain Scenic Area, Wushan Scenic Area, and West Lake Scenic Area, such as Bantou Mountain Community, Yuhuang Mountain Community, Shuicheng Bridge Community, Baitaling Community, and Shang Yang Street Community; and 8 communities around Gaoting Mountain Scenic Area, such as Gaocheng Village, Yanshan Village, Changmu Yuan Community, Sanyi Yuan Community, and Donglin Bridge Community, among others. In addition, approximately 15 communities have high accessibility. They are scattered in the central and eastern parts of the Shangcheng District. From the scale of residential areas, a total of 234 residential areas have 0 accessibility, accounting for 37.68% of the total number of residential areas. From the scale of communities, 45 communities have 0 accessibility, accounting for 23.08% of the total number of communities, including 12 communities on Jiubao Street, 7 communities on Kakeqiao Street, 6 communities on Pengbu Street, and 5 communities on Wangjiang Street, to name a few. Thus, a large proportion of areas lack park green space supply, that is, the Shangcheng District of green space accessibility space differences.

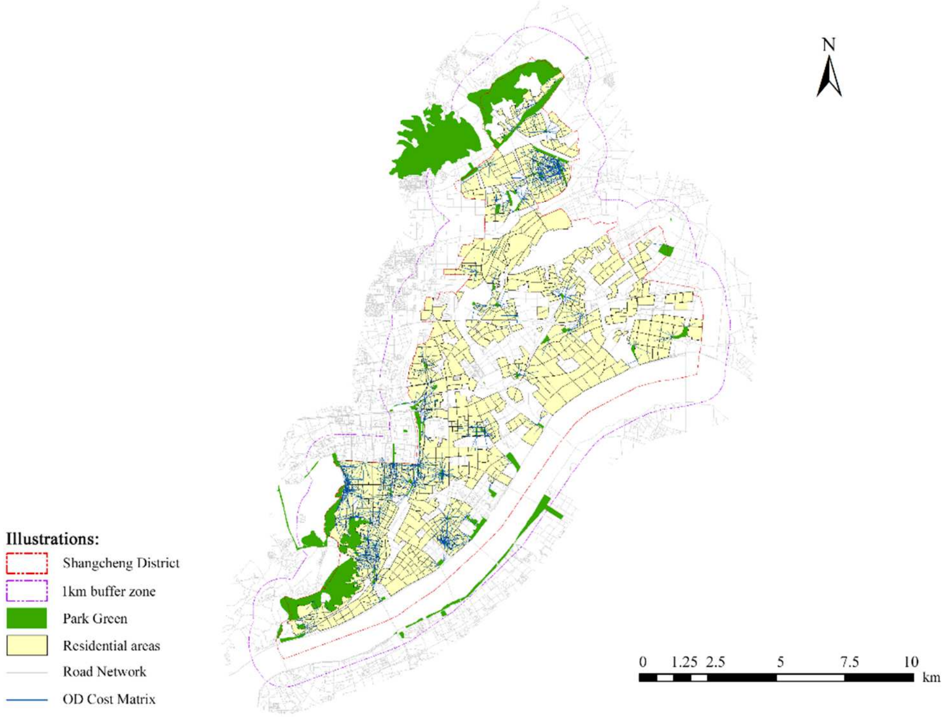

Fig. 4. OD cost matrix of walking for 15 minutes

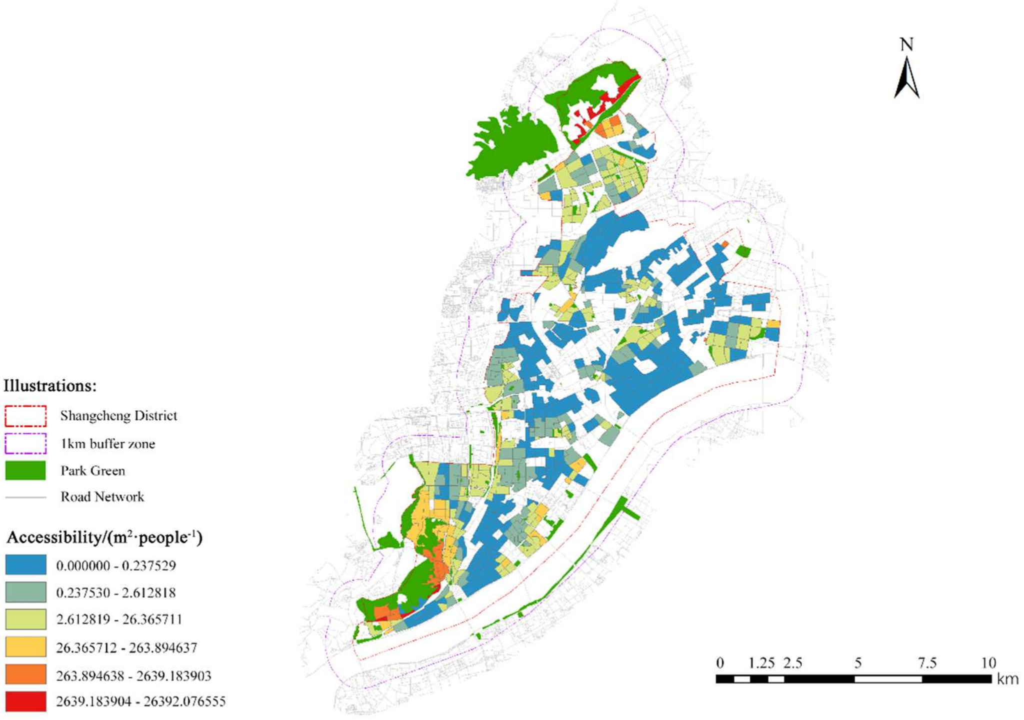

Fig. 5. Residential green space accessibility in Shangcheng District, Hangzhou

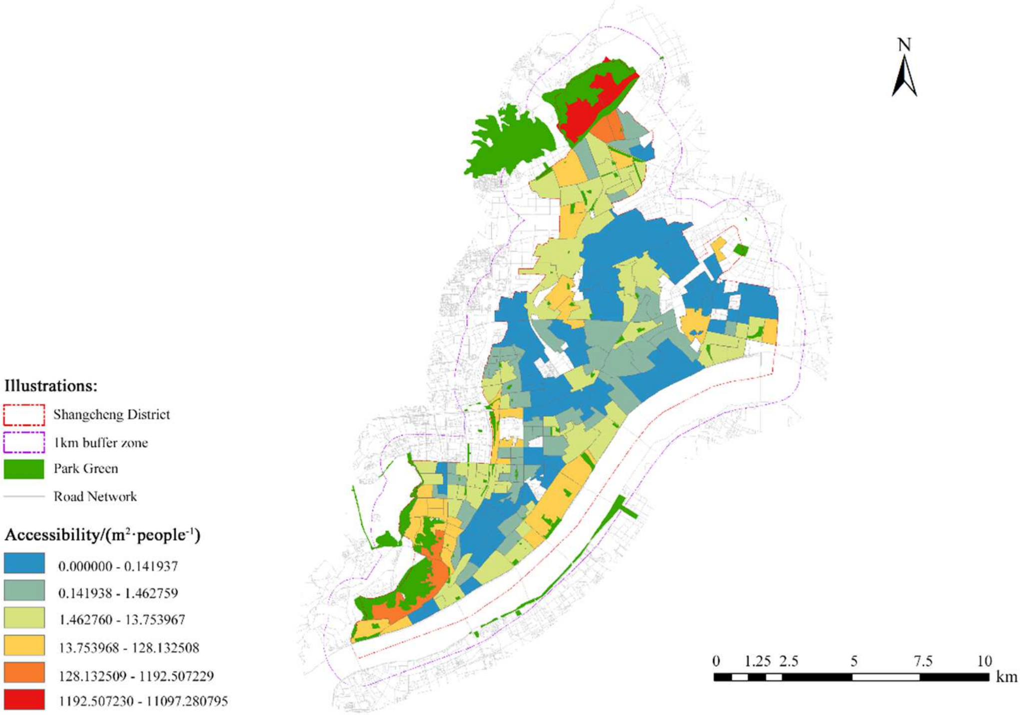

Fig. 6. Community-level green space accessibility in Shangcheng District, Hangzhou

Social equity evaluation

To scientifically reflect the social equity of the distribution of green park space in each community in the Shangcheng District, a Lorenz curve was drawn with the cumulative percentage of the resident population as the X-axis and the cumulative percentage of park green space accessibility as the Y-axis. From Figure 7, 90% of the population only has 8.24% of the green space supply, whereas the remaining 10% of the population has more than 90% of the green space supply. Based on the Lorenz curve, the Gini coefficient of park green space accessibility distribution in the Shangcheng District is 0.94. From Table 1, we can see a severe inequity in the disparity of park green space supply in the Shangcheng District.

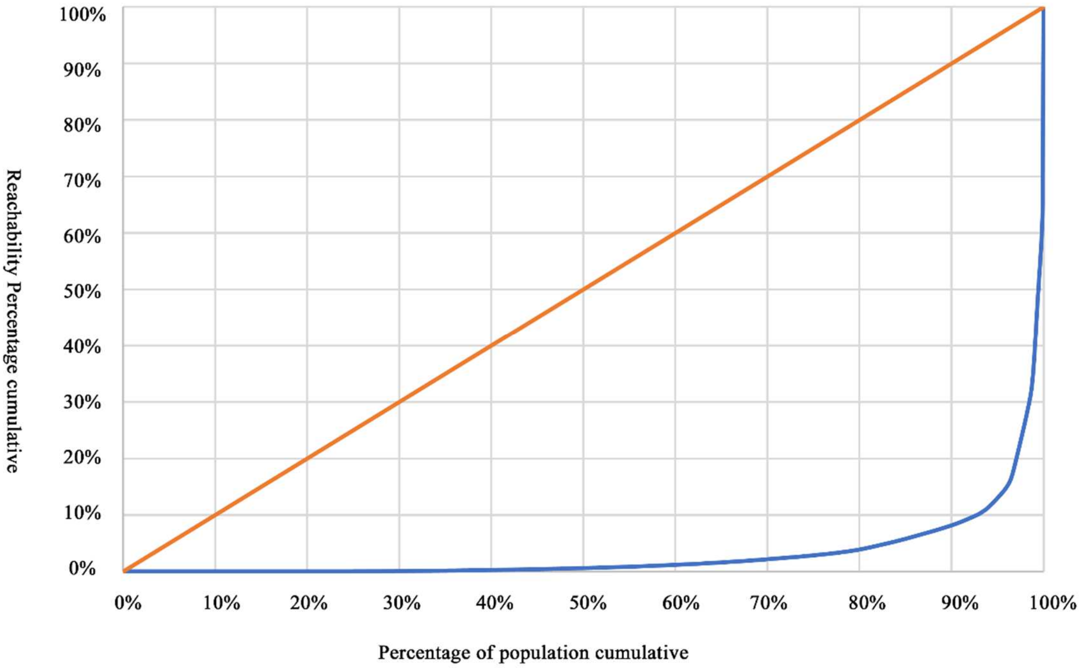

Fig. 7. Lorentz curve of accessibility distribution of green park space in Shangcheng District

Accessibility Impact Path QCA Analysis Results

Communities with 0 accessibility and communities around the Gaoting Mountain Scenic Area, Phoenix Mountain Scenic Area, and Mid-Levels Park that might make the analysis results more inaccurate were excluded, and 127 communities in the Shangcheng District were finally retained as QCA study cases. Considering that green areas and road networks outside the administrative boundaries of communities can impact the green space accessibility of communities, this study established a 900-m buffer zone for each community in this study on the basis of a 15-min walking distance. The data of the six causal conditions were calculated from each community plus the relevant data within the community buffer zone. The outcome variables of the QCA analysis were taken from the green space accessibility data obtained above.

When using the fsQCA analysis, each causal and outcome condition is considered a set, and each case has a corresponding affiliation score in these sets. The process of assigning an ensemble affiliation score to each case is calibration (Kallmuenzer et al., 2021). In this study, the three cross-over points for the outcome variable were set to the 75% quantile (full membership), 40% quantile (cross-over point), and 5% quantile (full non-membership) of the sample data, respectively (Fiss, 2011). Table 2 shows the calibration cross-over points for each variable.

Tab. 2. Calibration anchor points for each variable

Research Variables		Anchor point		
		Full membership	Cross-over points	Full non-membership
Causal conditions	Road network density/(m• m^{-2})	0.021057888	0.01289311	0.005831047
	Population density/(people•m^{-2})	0.059295525	0.024753251	0.002118685
	Number of entrances	27	11	2.3
	Park area/m^2	704984.8772	146975.0387	24189.78931
	Number of parks	14	6	1.3
	Shape index	1.787786933	1.506934931	1.24144138
Outcome condition	Green space accessibility /(m^2•$people^{-1}$)	6.093737694	1.385264789	0.057289787

Analysis results

This study used fsQCA 3.0 software to test the necessity of 127 community cases, and Table 3 presents the results. A consistency score greater than 0.9 is generally considered necessary (Schneider & Wagemann, 2013). As shown in Table 3, none of the 12 condition variables constitutes the necessary antecedents for high green space accessibility. These factors may impact green space accessibility in the form of history.

Tab. 3. Necessity detection of the single condition of the QCA method

Causal conditions	Consistency	Case coverage
Road network density	0.531794	0.665763
~Road network density	0.647092	0.687733
Population density	0.540834	0.657036
~Population density	0.632722	0.690341
Number of entrances	0.64753	0.765994
~ number of entrances	0.521643	0.583277
Park area	0.593148	0.792754
~Park area	0.594381	0.599497
Number of parks	0.596217	0.774714
~ number of parks	0.5846	0.602629
Shape index	0.641777	0.716913
~Shape index	0.542191	0.642038

This study set the original consistency threshold to 0.8, the PRI consistency threshold to 0.7, and the case frequency threshold to 1. It identified the core condition of each solution by comparing the nested relationship between the intermediate and the parsimonious solutions: the condition that appears in both the intermediate and the parsimonious solution is the core condition of that solution, and the condition that appears only in the intermediate solution is the peripheral condition (Covin & Tynon, 2009). Referring to Ragin's research findings, the results are presented as follows: ●indicates that the core condition is present; • indicates that the peripheral condition is present; ⊗ indicates that the core condition is missing; ⊗ indicates that the peripheral condition is missing, and space indicates that the condition can be both present and missing (Ragin, 2008). Table 4 shows the results of the QCA analysis and a detailed analysis of each grouping that induces high green space accessibility.

(1) Configuration H1 shows that when green space supply is sufficient, i.e., high park area and the number of parks, and more park entrances and exits are open, the surrounding communities will have high green space accessibility. The effects of road network density, population density, and park shape index on high green space accessibility are insignificant in this case. Typical cases conforming to this grouping are the Chungjinmen community, Youth Road community, Dongping Lane community, Dongpo Road community, and Wushan Road community around West Lake Scenic Area and Wushan Scenic Area; New Kaiyuan community, Kaixi community, Kwaixiang community, Old Zhejiang University community, and Jinghui community around the green areas along

the river close to the Sha River; Chengxing community adjacent to Qiantang River, CBD Park, and Forest Park. The surrounding area comprises 13 parkland communities such as Dingqiao Yuan community, Datang Yuan community, and Dylan community. The unifying feature of these communities is that they are surrounded by sufficient green space supply. Even in the less developed road networks around Dingqiao Yuan, Datang Yuan, and Dinglan communities, they have a high level of green space accessibility thanks to the abundant supply of green space in the surrounding parks.

(2) Configuration H2 shows that in the case of a small number of park entrances, a small number of parks, and a tiny park shape index, a larger park area allows for high green space accessibility to the surrounding community and that the size of the road network density and population density has no significant impact on high green space accessibility in this case. Typical cases that conform to this grouping are the Jing Yi community, Wu Fu community, Qian Tang community, Yun Xin community, Qian Yun community, Qian Jing community, Tong Xie Yuan community, and San Wei community. These communities are surrounded by a small number of parks but still achieve a high level of green space accessibility by relying on a large area of green park space.

(3) Configuration H3 shows that when the shape index of the green park space is small, that is, the shape of the green space is relatively regular, if the number of parks and entrances and exits is large and the road network density is high, the surrounding communities can have higher green space accessibility. In this case, the effect of population density and park area on the accessibility of high green space is insignificant. Typical cases conforming to this grouping are all six communities in Lakeside Street around the West Lake and Wushan scenic area: Dingan Road community, Liu Cuijing Lane community, Labor Road community, Xi Pailou community, Zijin community, Shang Yangcheng Street community, as well as Yaohua community, Jinjiang East Garden community, Yongjiang community, which are close to Qiantang River; and Blue Sky community near the Jiangnan Canal. These communities are in relatively more developed areas. Thus, the density of the surrounding road network is higher, with the surrounding environment characterized by having more intensive parks and green spaces such as West Lake and Wushan Scenic Area; or adjacent to the Jiangnan Canal, with rich green spaces along the river; then, it has more community-level parks around, with a more balanced spatial distribution. These communities rely on an abundance of parkland and a high number of park entrances, complemented by accessible transportation, to link supply and demand successfully and achieve a high level of green space accessibility.

(4) Configuration H4 shows that in the case of low road network density and population density, the number of parkland and entrances is high, and the parkland is more irregular. The surrounding community will obtain high green space accessibility, and the effect of the park area on high green space accessibility is insignificant in this case. Typical cases conforming to this grouping are the Qingheyuan community, Dingqiaoyuan community, Houzhuyuan community, Datangyuan community, Hexi community, Wuhuigang community, and Lan Yin community. Most of these communities are far away from the city center, the development remains immature, and the population density and road network density are relatively low. However, the sufficient number of surrounding parklands and the opening of more park entrances and exits, together with the high shape index of parklands, increase the area of accessible areas of parks and comprehensively improve the accessibility of green spaces in the area.

(5) Configuration H5 shows that in the case of low population density and regular green space shape, a larger park green space area and more park entrances can make the area achieve high green space accessibility. The effect of road network density and the number of green park spaces on high green space accessibility is insignificant. Typical cases conforming to this configuration are the Chungjinmen community, Dongpo Road community, Wushan Road community, Labor Road community, and Sanbao community, among others. These communities are characterized by their proximity to the West Lake Scenic Area and Wushan Scenic Area; or to Wangjiang Park, Century Garden, Forest Park, CBD Park, and Fisherman's Wharf Ecological Park, to name a few. The high degree of parkland supply and many entrances and exits around these communities improve the accessibility of green space in the area.

Tab. 4. Configuration analysis results of high green space accessibility

Condition Variables	High green space accessibility grouping				
	H1	H2	H3	H4	H5
Road network density			•	⨂	
Population density				⨂	⊗
Number of entrances	●	⊗	●	●	•
Park area	●	●			•
Number of parks	●	⨂	●	•	
Shape index		⨂	⨂	•	⊗
Consistency	0.830043	0.827273	0.842037	0.885859	0.876795
Original coverage	0.487165	0.232185	0.268787	0.234953	0.259308
Unique coverage	0.132462	0.0434369	0.0158899	0.00712305	0.00287658
Overall consistency			0.80642		
Overall coverage			0.57019		

The credibility of the QCA analysis results can be improved by robustness testing, and this study conducted robustness testing on the antecedent histories of high green space accessibility. First, the consistency threshold was increased from 0.8 to 0.85, and the resulting histories were entirely consistent. Second, the PRI consistency is increased from 0.7 to 0.75, and the resulting histories are a subset of the original histories. Finally, the case number threshold was increased from 1 to 2, and the resulting histories were a subset of the original histories. Robustness tests show robust results.

Conclusion

To effectively answer the impact of complex interactions among elements on green space accessibility, the current study explored the possible equivalent paths formed by combining elements at different levels. It then established the model of the impact path of green space social equity. It combined the 2SFCA, Lorenz curve and Gini coefficient method, and QCA to analyze the complex impact mechanism of green space, population, and transportation on the accessibility of green space from a configuration perspective. The following conclusions could be drawn:

(1) A large proportion of the green park space in Shangcheng District does not have the supply of green park space. And there is a serious situation of unfair supply of green space, and residents in the area have insufficient access to public green space resources.

(2) A single impact factor cannot constitute a necessary condition for high green space accessibility, indicating that high green space accessibility is the result of the combined action of multiple influencing factors, that is, multiple concurrent.

(3) This study employed the QCA method to discover five configurations that produce high green space accessibility. They embody multiple ways of achieving high green space accessibility in different areas. It shows that decision-makers can compare the cases with similar conditions among the five configurations that lead to high green space accessibility according to the population distribution, traffic conditions, and the current supply of green space in the area to achieve high green space accessibility with minimum cost and improve the overall social equity. Alternatively, under specific conditions, learning from less similar areas with high green space accessibility can be beneficial in determining how to optimize green space layout and transportation conditions to improve the accessibility of green space and overall social equity in the region.

Theoretical Insights

The theoretical contributions of the study are as follows. (1) This study provides an in-depth analysis of the impact of the synergistic linkage of three levels of factors: residents, traffic, and green space on the accessibility of high green space. It finds that the accessibility of high green space is not determined by one level of factors but depends on an antecedent grouping of six causal conditions at three levels. It also summarizes five configurations that influence the accessibility of high green space, which compensates for the lack of exploration of the linkage effect of factors in previous studies and helps attain a rigorous understanding of the complex mechanisms that lead to high green space accessibility. (2) This study is the first to introduce the QCA to the study of social equity in green park spaces. The QCA, based on a holistic perspective, is an ideal tool for understanding the complex phenomenon of high green space accessibility and deepens the understanding of the complex causal mechanisms of multiple factors affecting green space accessibility. The QCA is currently used in management, but this study also broadens the application area of the QCA.

Practical Insights

This study identified multiple path options for high green space accessibility and summarized the histological results for practice with the following insights. (1) The social equity of green space is affected by multiple factors. When economic, policy, land use, and other related conditions allow, increasing the area and number of parks and adding park entrances and exits are the main ways to improve the social equity of parks and green spaces. (2) If the above conditions cannot be met, giving priority to increasing the area of green park space can effectively improve the social equity of green space. (3) From the perspective of the increase in the number of parks, if the area of the park cannot be effectively increased, by maximizing the number of parks and the number of entrances and exits, such as the construction of pocket parks on vacant lots, high green accessibility can still be produced. (4) The road network density and population density around the green park space positively affect the social equity of the green space in the form of marginal conditions. The surrounding traffic conditions and population distribution should be considered in the site selection of the green park space.

To sum up, in the planning and design of green park space, the development plan of each region can be formulated according to the existing conditions of each region. Through the adaptation of multiple conditions under the "overall perspective", a differentiated development path is formed, which effectively improves the accessibility of the green space in regional parks, thereby improving the overall social equity of the green space.

Research limitations and future directions

In the current study, some limitations persist in the proposed research model of social equity impact pathways in green spaces and can be further extended in future research. (1) Owing to the limited availability of data, this study uses accessibility evaluation instead of social equity evaluation without considering the quality and function of the park itself, subjective feelings of residents, road congestion, and urban topography, to name a few. In the future, these aspects can be considered to obtain a complete social equity evaluation result of green areas. (2) In this study, a 15-min walk is selected as the travel mode and time cost threshold for residents to reach the green park space; meanwhile, the impact of different travel modes such as bus, subway, and private car and different time cost thresholds on the accessibility of the green park space can be considered later. (3) Although the model of high accessibility of parkland used in this study has already covered the influencing factors of residents, traffic, and green space, which previous studies have verified, inevitable omissions persist. Future studies can collect other potential influencing factors and research the grouping that affects green space accessibility and social equity. (4) This study selected the Shangcheng District as the research object. Its high green space accessibility grouping to other regions still needs further verification. In the future, relevant data from other cities can be collected to analyze further the grouping paths that produce high green space accessibility.

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