RESEARCH ON SUPPLY FAIRNESS EVALUATION AND OPTIMIZED LAYOUT OF URBAN GREEN SPACE IN XUZHOU QUANSHAN DISTRICT, CHINA

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Abstract. This study takes Xuzhou Quanshan District of China as the research object, firstly, the two-step floating catchment area method was used to evaluate the green space supply level; and then, Gini coefficient and Lorentz curve were used to evaluate the spatial distribution fairness of urban green space; finally, the optimization layout strategy was put forward in three stages. The results showed that: 1) the green space supply of different sub-district varies greatly, the supply level in the south is higher than that in the north. There are three sub-districts lower than the standard of 5.5 m^2/person. 2) The average supply of green space in 453 residential areas is 12.66 m^2/person, as many as 68.3% of the residential areas did not meet the 14.6 m^2/person, of which 181 residential areas were less than 5.5 m^2/person, accounting for 40.0% of the total. 3) The Gini coefficient of the distribution of green space in 453 residential areas has reached 0.3659, which is close to the warning level. 4) After the optimization layouts, a total of 243.792 hm^2 of green space was added. The residential-level Gini coefficient was reduced by 31.7% to 0.2499, meanwhile the Gini coefficient of each sub-district was less than 0.4.
Keywords: *Lorentz curve, environment, Gini coefficient, layout optimization, park, landscape*

Introduction

Urban green space is an important part of the urban ecosystem, which can protect the urban biodiversity (Coppel and Wustemann, 2017), and improve the quality of the urban ecological environment by regulating the microclimate (Amani-Beni et al., 2021), noise reduction (Xu and Li, 2017) and air purification (She et al., 2020). At the same time, urban green space is also an important place for urban residents to relax and have social activities, which can improve the physical and mental health of urban residents (Barton and Rogerson, 2017; Zhang et al., 2021; White et al., 2021). In the case of limited public resources, the urban green space should not only meet the requirements in quantity, but also consider the balance of spatial distribution (Liu et al., 2022). The European Environment Agency has identified green space that can be reached within 15 minutes as one of the criteria for urban environmental quality evaluation. The 10-Minute Walk project in the US aims to ensure that residents could reach the park within 10 minutes, while the UK Natural England organization recommends that all residents could reach green space above 2 hm^2 within 300 m (Tu et al., 2019; Roberts et al., 2021).

For a long time, the evaluation of urban green space in China has been based on the indicators of per capita green space area and greening rate (Zhang et al., 2022). With the continuous improvement of the urban population size, disposable income, and quality of life in China, these evaluation indicators have exposed many deficiencies (Zeng et al., 2022). Although these evaluation indicators can guarantee the number of green spaces,

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the actual spatial distribution of green spaces cannot meet the needs of people (Shi and Tao, 2020; Kuang et al., 2021). Therefore, the insufficient supply and imbalance between supply and demand of urban green space should be highly valued by urban managers and professional scholars. Evaluating the supply equity of urban green space and optimizing the layout are conducive to the improvement of urban ecological environment and the promotion of residents' health (Wang et al., 2022), which can ensure the fair allocation of urban green space resources.

In recent years, the research on the fairness of urban green space supply mainly focuses on the following two aspects: on the one hand on spatial analysis and mainly considers its accessibility in the evaluation of green space fairness. E.g. Yu et al. (2022) quantitatively analyzed the supply status of urban green space in the central city of Fuzhou city, Fujian Province; Liu et al. (2019) calculated the accessibility resistance and service range of urban green space in Baotou city based on transportation network; Fan et al. (2017) measures the accessibility of Shanghai residents to different types of urban green space by building the "Green Accessibility Index" (GAI); Xing et al. (2020) has quantitatively analyzed the balance between green space and resident population distribution in the Zhengzhou city based on the accessibility; Peng and Gu (2020) studied the accessibility of green space and the supply and demand services of the typical social vulnerable groups in Yangzhou city. On the other hand, on quantifying spatial unfairness with Gini coefficient in economics (Li et al., 2019). Zhang et al. (2022) used the Gini coefficient to study the difference of green space rate in different cities; Yue et al. (2017) used Lorentz curve and Pearson's correlation coefficient to study the correlation between green space distribution and low-income population; Wu and Fang (2020), Sun et al. (2020) used the Lorentz curve and the Gini coefficient to evaluate the overall fairness of the urban green space.

Most of the above studies neglected the most widely distributed community parks and small gardens in the city. The population data used the street-scale census data, and the actual population data of residential areas were not used, which could not reflect the fairness of urban green space supply in smaller space units. In addition, most of the existing studies stay in the stage of supply and demand evaluation, and do not further propose optimal layout methods, which cannot provide practical reference for urban green space planning. Therefore, this study takes Xuzhou Quanshan District of China as the research object, and collects 453 residential districts and road network data. Firstly, the 2SFCA (two-step floating catchment area, 2SFCA) method was used to evaluate the green space supply level in the study area. And then, Gini coefficient and Lorentz curve were used to evaluate the spatial distribution fairness of urban green space; Finally, the optimization layout strategy was put forward in three stages to eliminate the service blind area of urban green space. In order to provide data reference and scientific basis for optimizing the urban green space system and improving the service level of urban green space.

Materials and methods

Study area overview

Quanshan District is located in the southwest of Xuzhou City of China, connected with Yunlong District to the east, Gulou District to the north and Tongshan District to the south. Quanshan District is located in the northern temperate zone, mainly with plain terrain, which is a warm temperate humid and subhumid monsoon climate. It has four

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distinctive seasons, with an annual average temperature of 14.5 degrees, an annual frost-free period of about 210 days, and an annual precipitation of about 802.4 mm (Wang, 2021). In Quanshan District, there are famous scenic spots such as Yunlong Lake, Yunlong Mountain and Quanshan Forest Park. It is the economic, education and medical center of Xuzhou, with a high residential density. The total area of the study area is 78.2 km^2, containing 11 sub-district offices and 453 residential areas (*Fig. 1*).

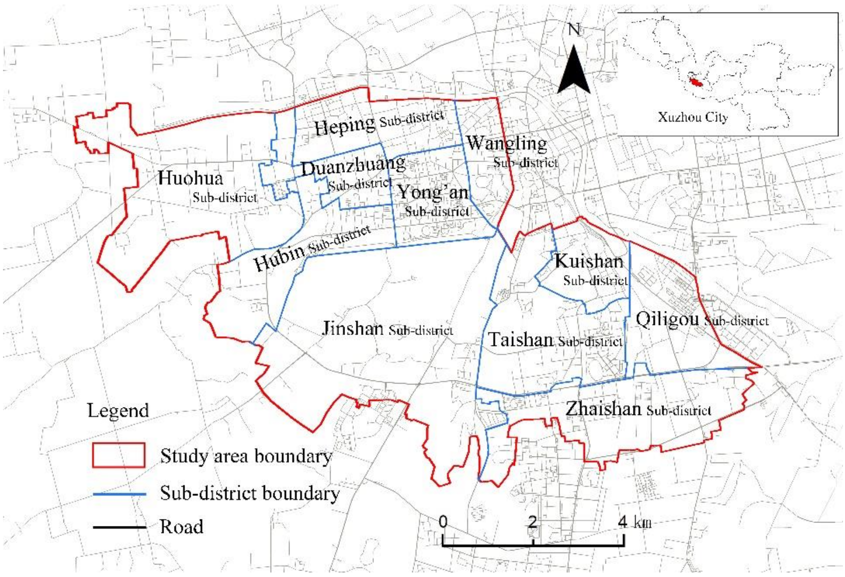

***Figure 1.** Overview of the study area*

Data source and processing

The urban green space data used in this study were derived from the GoogleMap 2020 remote sensing images with a resolution of 0.25 m, and then manual visual interpretation was used to draw the distribution vector map of urban green space (*Fig. 2*). According to the classification standard of green space in China, urban green space is divided into four categories, i.e. comprehensive park, community park, special park and neighborhood park. The definition, scale, service radius and area ratio of each green space type in the study area are shown in *Table 1*. Belt green space with a width of less than 6 m and roadside green space inaccessible to residents were not included as research subjects.

***Table 1.** The classification and description of urban green space in the study area*

Type	Service Radius (m)	Area Definition	Total Area (hm^2)	Area Ratio	Type Description
comprehensive park	2000	> 10 hm^2	998.753	71%	Suitable for all kinds of outdoor activities, with perfect recreation and service facilities
community park	1000 500	5-10 hm^2 1-5 hm^2	188.309	13%	With basic recreation facilities, to provide services for the daily activities of the surrounding residents
special park	1000	-	137.366	10%	With a specific content and form, e.g. botanical garden, theme park
neighborhood park	300	< 1 hm^2	82.629	6%	Small scale, which is convenient for residents to enter nearby

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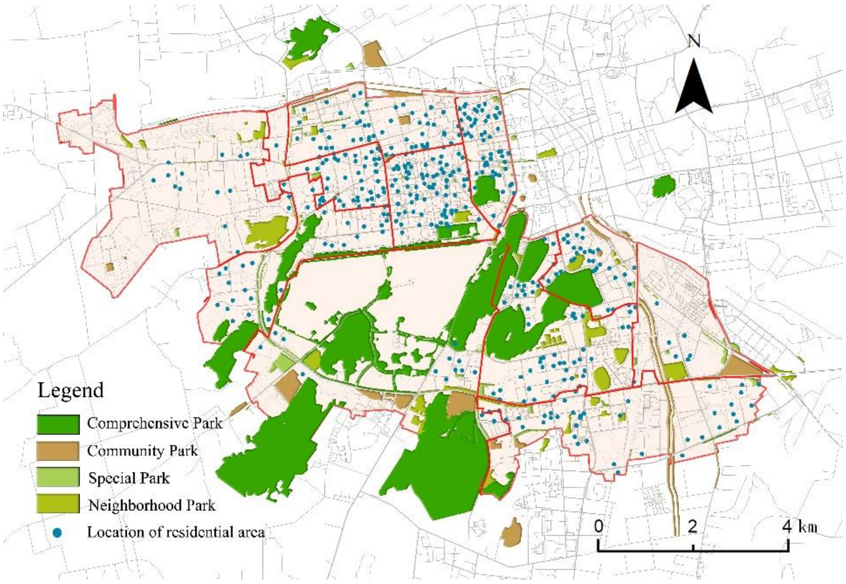

Figure 2. *Location map of urban green space and residential area in Quanshan District*

The specific information of 453 residential districts in Quanshan District was collected from Bigemap in 2020, and the entrances and exits of each residential district were extracted as the source point, and then the population data of the residential district was matched to the source point. Demographic data comes from the Internet data captured by a web crawler, mainly including "Anjuke" website, Tencent real estate website, 58 City website and "Fangtianxia " website. The population distribution map of each residential district in the study area is shown in *Figure 3*. The road network data were extracted from the main urban roads of Xuzhou city using Open Street Map, and the shortest distance from the residential district to the urban green space was calculated by using the OD cost distance in Arc Gis.

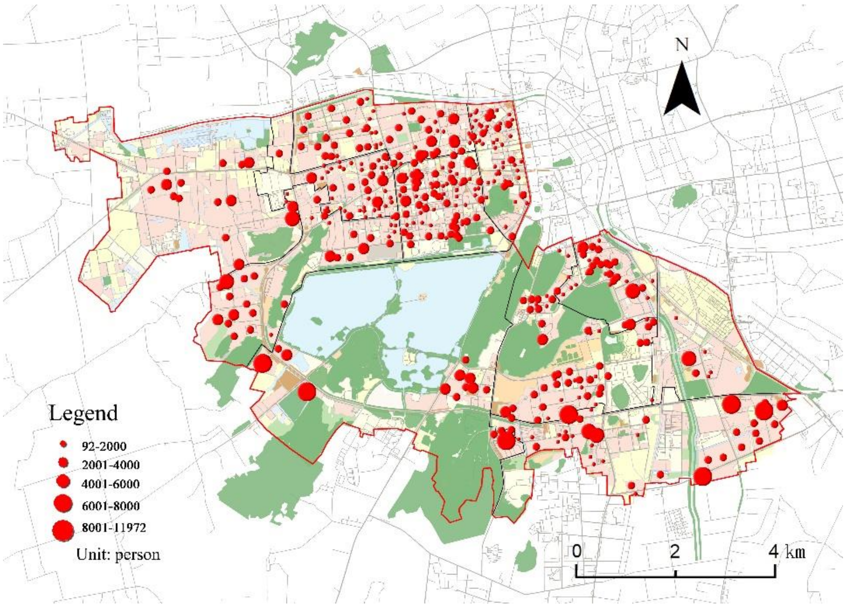

Figure 3. *Population distribution map of residential areas in Quanshan District*

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Study method

The 2SFCA: The 2SFCA evaluates the supply capacity of urban green space from the perspective of accessibility (Ren and Wang, 2021). The principle of 2SFCA is to obtain the accessibility of two objects by calculating the spatial distance between each other. It can be implemented by Python programming under the ArcGIS platform. When calculating the accessibility of urban green space, the 2SFCA considers both supply and demand factors, and its calculation result is more comprehensive and simpler. According to the different service radius, the supply capacity within different types of urban green space service range can be obtained by using the 2SFCA method. The formula is as follows:

$$R_{mn} = \frac{S_{mn}}{\sum_{i \in (d_{imn} \le d_m)}^{H} K_i \times F(d_{imn})} \quad \text{(Eq.1)}$$

where R_{mn} is the per capita supply capacity of the nth patch of category M green space; S_{mn} is the area of the nth patch; d_m is the service radius; d_{imn} is the distance between the ith residential district and green patches; H is the number of residential district within the service radius; K_i is the population of ith residential district; $F(d_{imn})$ is the Gauss equation considering the space friction problem.

The second step is to calculate the total area of green space within the spatial scope of each residential district, so as to obtain the cumulative supply level. The formula is as follows:

$$G_i = \sum_{m \in (d_{imn} \le d_m)} R_{mn} \times F(d_{imn}) \quad \text{(Eq.2)}$$

where G_i is the cumulative supply level of residential district i; $m \in (d_{imn} \le d_m)$ is the total number of green patches whose distance from residential district i is less than the service radius; Other characters have the same meaning as *formula 1*.

The Lorentz curve and the Gini coefficient: Lorentz curve and Gini coefficient are two concepts in the field of economics, and they are commonly used fairness evaluation indicators. With the expansion of discipline boundaries, these two indicators are also gradually used to evaluate whether the distribution of social resources is fair (Chen et al., 2021; Han et al., 2021). This study defines the Lorentz curve as a function between the cumulative proportion of the resident population and the proportion of green space resources owned by the population in this area. The horizontal axis of the Lorentz curve is the proportion of cumulative population of the community, and the vertical axis is the proportion of cumulative green space supply. The smaller the slope of the curve, the higher the degree of spatial mismatch between green space resources and population distribution, and the greater the degree of inequality. The Gini coefficient can be calculated from Lorentz curve, and its value is between 0 and 1. The smaller the value, the better the fairness. The formula is as follows:

$$Gini = 1 - \sum_{i=1}^{n} (x_{i+1} - x_i)(y_{i+1} + y_i) \quad \text{(Eq.3)}$$

where n is the number of residential district; x_i is the proportion of the cumulative population; y_i is the proportion of the cumulative ownership of urban green space.

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Results and discussion

Analysis of urban green space supply based on accessibility

According to the planning standards proposed by China and relevant academic studies, residents should arrive at the comprehensive park in less than 30 minutes, the community park in less than 15 minutes, and the neighborhood park in less than 5 minutes. The walking speed of normal adults is about 1.2 m/s, and the walking distance in one minute is about 70 meters (Luo, 2016). Therefore, in this study, the service radius of the comprehensive park is set as 2000 m, and the service radius of the community park is set as 500 m (area 1-5 hm^2) and 1000 m (area 5-10 hm^2), and the service radius of the neighborhood park is set at 300 m. After field investigation, the scale of special parks in the research area is similar to that of community parks, so its service radius is also set as 1,000 m.

According to *equation 1* of the 2SFCA, the calculation results of urban green space supply in Quanshan District of Xuzhou City based on accessibility can be obtained (*Fig. 4*). It can be seen from *Figure 4* that the green space supply of different sub-district varies greatly, on the whole, the supply level in the south region is high, while the supply level in the north region is low. The highest supply level is Jinshan sub-district, located in the south of Quanshan District, up to 43.625 m^2/person. Next is Taishan sub-district and Hubin sub-district, with supply level of 21.505 m^2/person and 20.695 m^2/person, respectively. The green space supply level of five sub-districts is between 5.5 m^2/person and 14.6 m^2/person, followed by Zhaishan Sub-district (14.250 m^2/person), Kuishan Sub-district (13.780 m^2/person), Yong'an Sub-district (10.665 m^2/person), Qiligou Sub-district (9.583 m^2/ person) and Huohua Sub-district (7.227 m^2/person). There are three Sub-districts lower than the standard of 5.5 m^2 per capita green space in the urban area stipulated by the National Ecological Garden City, i.e. Duanzhuang Sub-district (5.127 m^2/person), Wangling Sub-district (5.119 m^2/person), and Heping Sub-district (2.684 m^2/person).

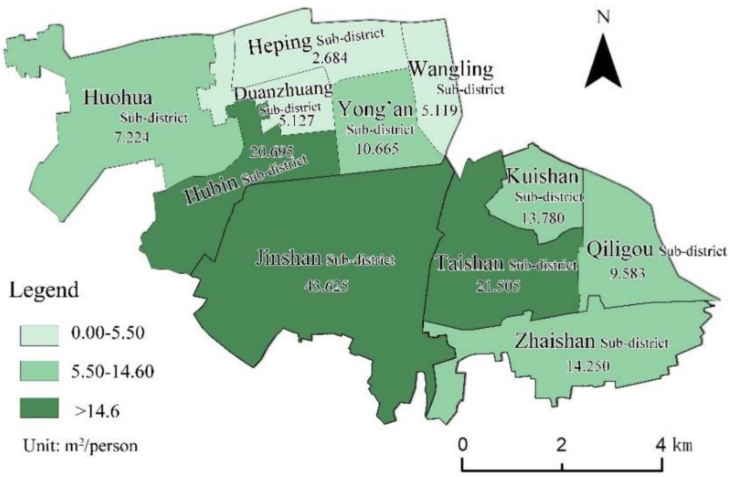

Figure 4. *Calculation results of green space supply of sub-districts in Quanshan District*

Jinshan Sub-district has Yunlong Lake, Binhu Park and other comprehensive parks with a wide service radius, and the building density is low, the development intensity control is strict. Taishan Sub-district has Taishan Park, Pengzu Garden and Kuishan Park,

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and the population density is very low; Hubin Sub-district is adjacent to woniu mountain on the left and Yunlong Lake and Zhushan Park on the right, providing a large number of green spaces for residents. Therefore, the supply level of green space in these three sub-districts is higher than others. The supply level of green space in northern old urban areas i.e. Heping Sub-district, Wangling Sub-district and Duanzhuang Sub-district is low. The main reason is that the old urban area was built early, the building density in the residential area was high, there were many commercial facilities, and there was a lack of large-scale comprehensive parks and neighborhood gardens.

By calculating 453 residential areas in Quanshan District according to *formula 2*, the per capita supply of urban green space in each residential area can be obtained (*Fig. 5*). The average supply of green space in 453 residential areas is 12.66 m^2/person, and the highest supply value is Jincaijiayuan Community, which is 88.2 m^2/person; there are 144 residential areas with the average number of green space supply exceeding 14.6 m^2/person, accounting for 31.7% of the total. As can be seen from *Figure 5*, these residential areas are mainly distributed in Hubin Sub-district, Jinshan Sub-district and Taishan Sub-district, close to Yunlong Lake and Yunlong Mountain Scenic Area, surrounded by large parks such as Yunlong Park, Binhu Park and Pengzu Park, so the per capita supply level of urban green space is high. As many as 68.3% of the residential areas did not meet the 14.6 m^2/person standard stipulated in the 13th Five-Year Plan of China, of which 181 residential areas were less than 5.5 m^2/person, accounting for 40.0% of the total. Most of these residential areas are located in the north and southeast of Quanshan District, with few comprehensive parks around. In the next step, when optimizing the layout, increasing green space in these areas should be considered first.

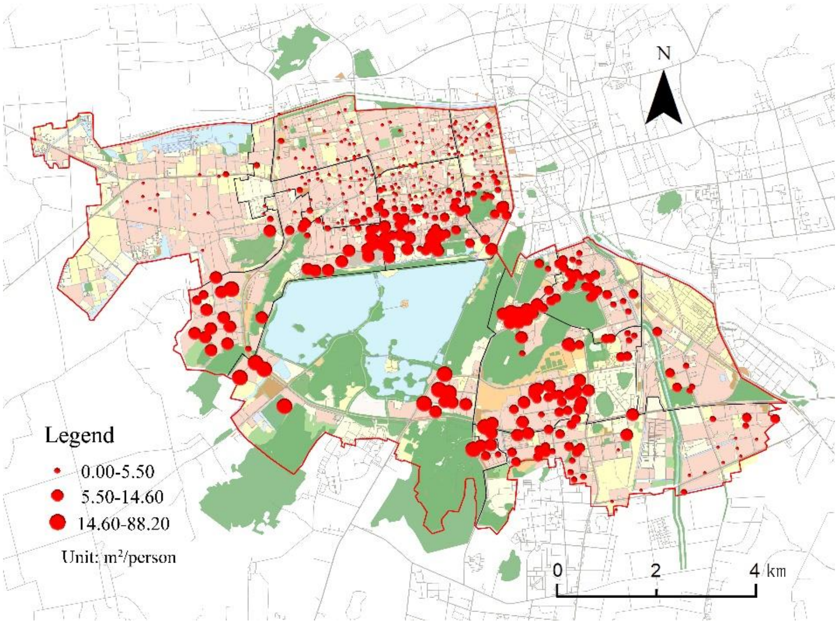

Figure 5. *Calculation results of green space supply of residential areas in Quanshan District*

Analysis of the fairness evaluation of urban green space

Lorentz curve and Gini coefficient were used to evaluate the fairness of green space distribution in Quanshan District. On the whole, the fairness of green space distribution in Quanshan District is higher in the South than in the north, and higher in the West than

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in the East (*Fig. 6*). Taking 453 residential areas as evaluation units, the Gini coefficient of the distribution of the urban green space in Quanshan District was calculated using *equation 3*, and then the Lorentz curve was depicted (*Fig. 6a*). According to the calculation results of *Figure 6a*, the Gini coefficient in 453 residential areas is 0.3659. According to international practice, the Gini coefficient exceeding 0.4 indicates a large gap in resource allocation, which may cause a series of social problems. While the Gini coefficient of the spatial distribution of green space in the 453 residential areas in Quanshan District has reached 0.3659, which is close to the warning line, indicating that the fairness of the spatial distribution of green space in the research area should be paid enough attention.

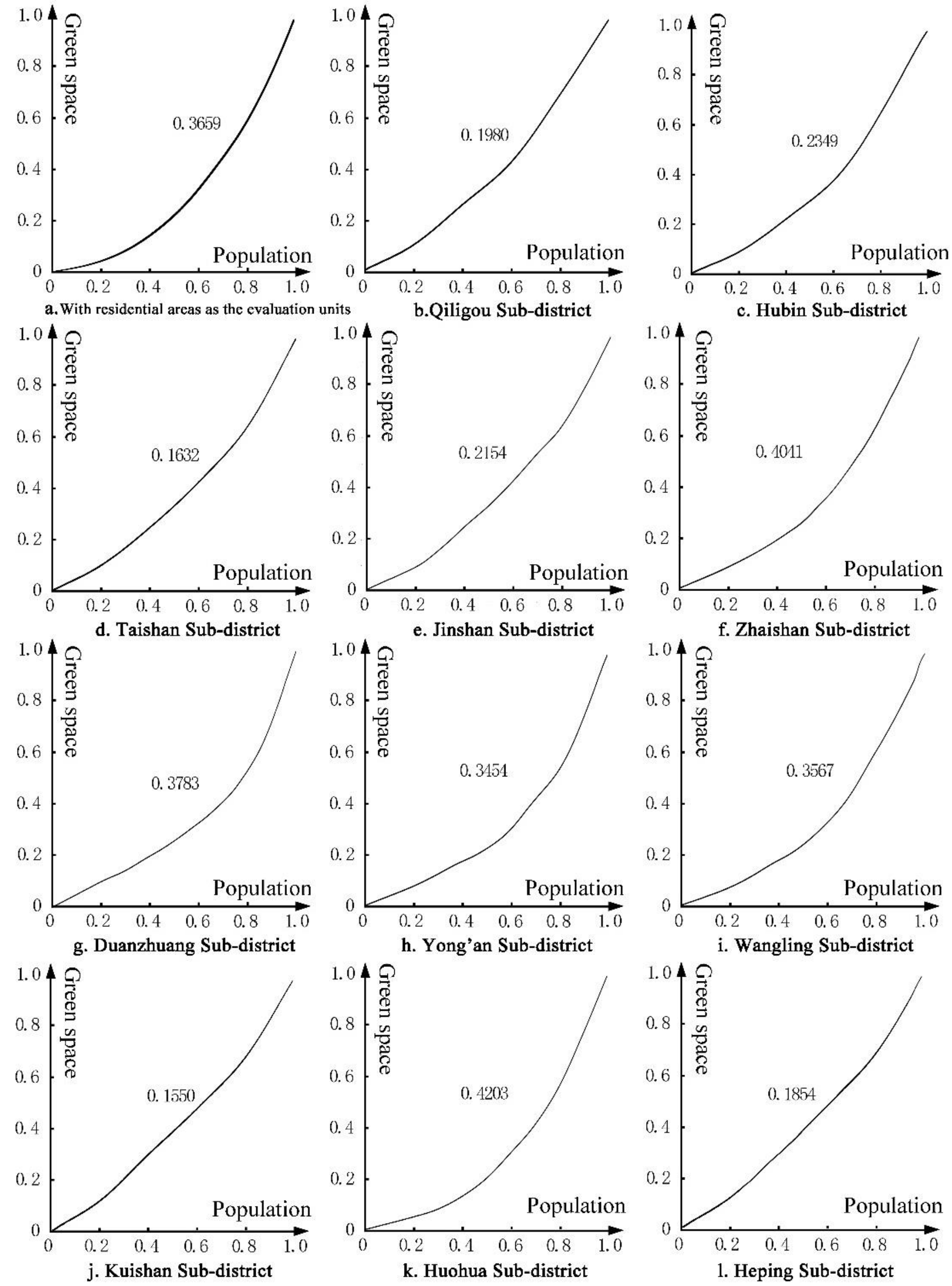

Figure 6. *Lorentz curve and Gini coefficient of sub-districts in Quanshan District*

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Then the Gini coefficient and Lorentz curve of green space distribution are calculated with 11 sub-districts as the evaluation unit, the analysis results are shown in *Figure 6b-6l*. It can be seen from the results that the Gini coefficient of two sub-districts exceeds 0.4, i.e. Huohua Sub-district (0.4203) and Zhaishan Sub-district (0.4041). It shows that the distribution of urban green space in these two sub-districts is unfair. The west of Huohua Sub-district is dominated by industrial land and agricultural land, and there is a lack of accessible green space; Zhaishan Sub-district has a large gap between the east and the west, with a large population density in the East and less green space, while the west is just the opposite. The Gini coefficient of Taishan Sub-district, Jinshan Sub-district and Hubin Sub-district is 0.1632, 0.2154 and 0.2349, respectively. Meanwhile, the per capita green space area is also high, with 21.505 m^2, 43.625 m^2 and 20.695 m^2 respectively, indicating that the supply of green space resources in these three sub-districts is sufficient and the distribution is fair. The Gini coefficient of Heping Sub-district, Wangling Sub-district and Duanzhuang Sub-district is 0.1854, 0.3567 and 0.3783, respectively, but the per capita green space area is less than 5.5 m^2, showing the phenomenon of low per capita green space but high fairness. This is mainly because the green space of the three sub-districts is evenly distributed but the total amount is insufficient.

Optimize layout strategy

Based on the analysis of supply and demand of urban green space, the service blind area of urban green space in Quanshan District should be eliminated in combination with the urban status quo, and the service level and space supply fairness of urban green space should be improved. This study will be divided into three stages to optimize the spatial layout of the urban green space by simulation, i.e. with the short-term (3-5 years), medium-term (8-10 years) and long-term (15 years) as the time nodes. In order to verify the rationality of the layout of new green space, the per capita green space and Gini coefficient are calculated after optimizing the layout at each time node, hoping to enhance the supply of urban green space while promoting the fair allocation of space.

The supply of urban green space in Hubin, Jinshan and Taishan Sub-districts is large, and the Gini coefficient is reasonable, so the number of urban green space does not need to be increased during optimization. Zhaishan and Huohua Sub-district with low per capita green space supply and high Gini coefficient should be considered when optimizing the layout. The supply of urban green space in Hubin, Jinshan and Taishan Sub-districts is large, and the Gini coefficient is more reasonable, so the number of urban green space does not need to increase when optimized. The optimization methods mainly include: 1) select abandoned industrial areas to be transformed into comprehensive parks; 2) transform some small vacant lots around residential areas into community parks; 3) build small neighborhood parks, such as urban pocket parks, in areas with dense residential buildings.

The optimized layout results of urban green space in Quanshan District are shown in *Figure 7*. In the first stage of optimization, a total of 87.73 hm^2 of urban green space will be added, including 54.96 hm^2 of comprehensive parks and 29.77 hm^2 of community parks. In the first stage of optimization, the abandoned land on both sides of Kui River in Zhaishan Sub-district and the abandoned land north of Huohua Road in Huohua Sub-district are transformed into medium and large comprehensive parks, and the wasteland and riverside open space in Duanzhuang and Wangling Sub-district are transformed into community parks and neighborhood park. The calculation results after optimization show that: the supply level of green space in the surrounding areas has

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increased significantly, the per capita supply level of urban green space in 453 residential areas has increased from 12.660 m^2 to 13.374 m^2 and add 18 new residential areas that meet the standard (>14.6 m^2/person). The per capita green space supply of Zhaishan Sub-district exceeded 14.6 m^2, reaching 15.878 m^2; The number of sub-districts whose per capita green space supply does not reach 5.5 m^2 is reduced from 3 to 1 (Heping Sub-district). The residential-level Gini coefficient was reduced by 10.96% to 0.3258, meanwhile the Gini coefficient of each sub-district decreased by about 5% on average.

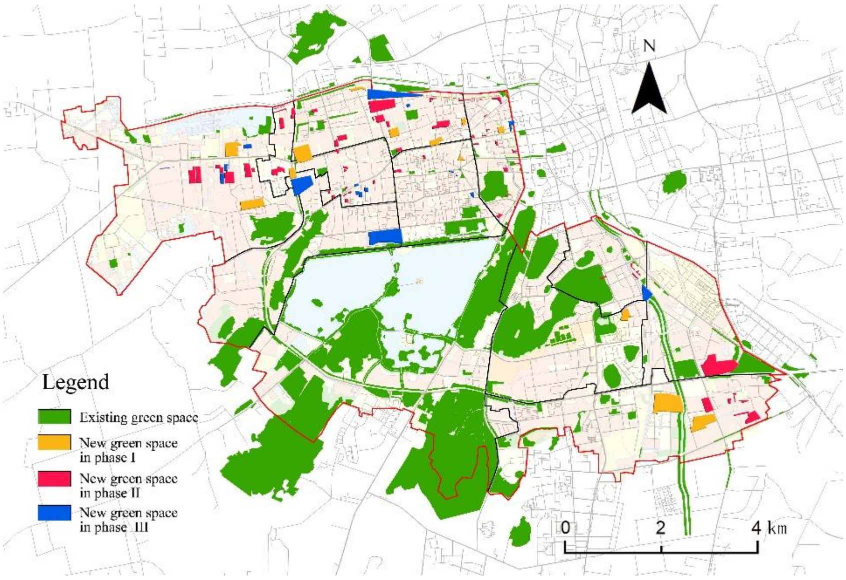

Figure 7. *Optimize the layout of new urban green space in three stages by simulation*

The second stage is mainly optimized for the old urban area in the north of Quanshan District and Qiligou Sub-district in the southeast. A total of 100.024 hm^2 urban green space will be added, including 32.757 hm^2 of comprehensive park, 47.862 hm^2 of community parks and special parks, and 19.405 hm^2 of neighborhood parks. The calculation results after optimization show that: the per capita green space supply in the northern old urban areas has been significantly improved, the per capita supply in 453 residential areas exceeded 14.6 m^2, which increased from 13.374 m^2 to 14.705 m^2; and add 15 new residential areas that meet the standard (>14.6 m^2/person). The per capita supply in Heping Sub-district has been increased from 2.684 m^2 to 6.104 m^2, and all sub-districts exceeded the minimum standard of 5.5 m^2/person. The residential-level Gini coefficient was reduced by 13.54% to 0.2817.

In the third stage, 56.038 hm^2 of urban green space will be added, including 30.463 hm^2 of comprehensive park, 19.125 hm^2 of community parks and special parks, and 6.45 hm^2 of neighborhood parks. The comprehensive park is mainly arranged in the Hubin Sub-district, and the neighborhood park is mainly distributed around the old residential areas. The calculation results after optimization show that: the per capita supply in 453 residential areas has increased to 15.451 m^2, the per capita supply of 6 new residential areas exceeded 14.6 m^2/person. The residential-level Gini coefficient was reduced by 31.7% to 0.2499, meanwhile the Gini coefficient of each sub-district decreased by about 7% on average, and the value was less than 0.4.

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After the three optimization layouts, a total of 243.792 hm^2 of urban green space was added. The per capita green space supply of all 11 sub-districts is more than 5.5 m^2, and 7 sub-districts exceed the standard of 14.6 m^2 (*Fig. 8*). Among them, Heping Sub-district changed the most, increasing from 2.684 m^2 to 7.526 m^2, up 180%; secondly, Huohua Sub-district increased from 7.224 m^2 to 14.822 m^2, up 105%. Wangling, Duanzhuang and Qiligou Sub-district also changed greatly, with growth rates of 72.9%, 61.5% and 55.5%, respectively. Compared with before optimization, the number of residential areas with per capita green space supply less than 5.5 m^2 has been reduced from 181 to 53, and the supply of urban green space in 128 residential areas has been improved.

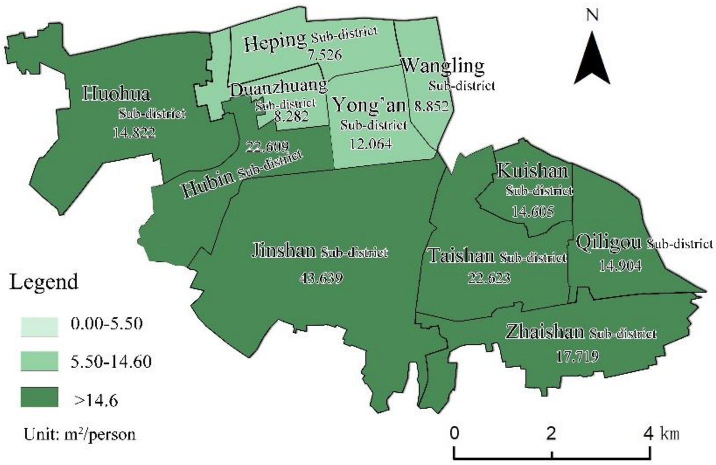

Figure 8. *Calculation results of green space supply in each sub-district after three optimization*

The number of residential areas between 5.5 m^2 to 14.6 m^2 increased from 128 to 217, and the number of residential areas greater than 14.6 m^2 increased from 144 to 183 (*Fig. 9*). The per capita supply of 400 residential areas is more than 5.5 m^2, accounting for 88.3% of the total and 183 residential areas exceeded 14.6 m^2, accounting for 40.4% of the total. According to the calculation results, after three optimizations, the supply level of urban green space in Quanshan District has been greatly improved, the spatial distribution of green space is more equitable, the blind area of urban green space service has been further eliminated, the service level of urban green space has been improved, and the expected effect has been achieved.

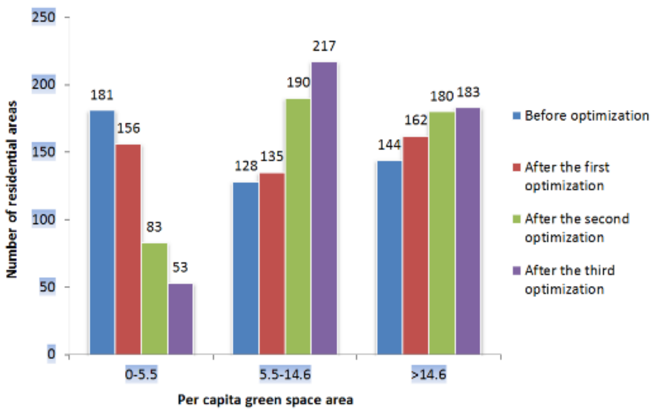

Figure 9. *The changes of per capita green space in residential areas*

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Discussion

Ma et al. (2022) and Li et al. (2019) set the per capita green space standard at 13.68 m^2 and 20.1 m^2 respectively when studying the relationship between supply and demand. Below this standard, it is considered that the green space supply is not up to standard. In this study, according to the 13th Five-Year Ecological Environment Protection Plan of China, the standard of per capita green space is divided into three levels: 0-5.5 m^2, 5.5-14.6 m^2 and greater than 14.6 m^2. This division method is more in line with the actual situation of Xuzhou City. Peng and Gu (2020) and Zhang et al. (2022) set the service radius of comprehensive parks and community parks as 5000 meters and 2000 meters in the study. In this study, the service radius of the parks was set at 2000 m, 1000 m, and 500 m respectively according to the area of the park, which makes the calculated results more reasonable.

In this study, it was calculated that the Gini coefficient of green space distribution in 453 residential areas in Quanshan District was 0.3659, which is basically consistent with the calculation results of the Gini coefficient of green space distribution in Xuzhou city by Xue et al. (2019), Li et al. (2019) and Ma et al. (2022). The value of 0.3659 is close to the warning level, indicating that the fairness of green space distribution should be paid enough attention.

The fairness of urban green space should not only pay attention to the urban green space rate, per capita urban green space area and other indicators, but also pay attention to the per capita green space in the area from the perspective of accessibility and establish the concept of green space fairness. Due to the plot ratio, high green space rate does not mean high per capita green space, and high per capita green space does not mean that the spatial distribution of green space is fair. Therefore, the Gini coefficient for different spatial scales can effectively reflect the spatial fairness of urban green space.

When studying the supply of urban green space, limited by remote sensing image technology, this paper failed to obtain the impact of green space vegetation types and other factors on the service capacity of urban green space, and did not consider the preferences of different groups for urban green space design. It only divided different urban green space grades through area standards and map discrimination. Using the 2SFCA, only the friction of space distance is considered, and the influence of travel mode, traffic conditions and terrain on accessibility is not considered. At the same time, the research group is more generalized, without distinguishing different age, gender, income, and physical condition.

Therefore, the future research should combine the following two points: first, considering the differences between travel modes in combination with the actual situation, so as to comprehensively and systematically analyze the fairness of urban green space; Second, the layout optimization of urban green space should widely listen to the opinions of the public, consider the different needs of different groups for urban green space, and integrate it into the urban green space planning.

Conclusions

Based on the residential area data, this study discusses the spatial fairness of urban green space in Quanshan District, Xuzhou City. First, the 2SFCA was used to evaluate the green space supply in the study area, and then the Gini coefficient and Lorentz curve were used to evaluate the spatial distribution fairness of urban green space. Finally, the optimization layout strategy is proposed in three stages. The results show that:

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The green space supply of different sub-district varies greatly, on the whole, the supply level in the south region is higher than that in the north region. The highest supply level is Jinshan sub-district, located in the south of Quanshan District, up to 43.625 m^2/person. Next is Taishan sub-district and Hubin sub-district, with supply levels of 21.505 m^2/person and 20.695 m^2/person, respectively. The green space supply level of five sub-districts is between 5.5 m^2/person and 14.6 m^2/person, followed by Zhaishan Sub-district (14.250 m^2/person), Kuishan Sub-district (13.780 m^2/person), Yong'an Sub-district (10.665 m^2/person), Qiligou Sub-district (9.583 m^2/person) and Huohua Sub-district (7.227 m^2/person). There are three sub-districts lower than the standard of 5.5 m^2 per capita urban green space in the urban area stipulated by the National Ecological Garden City, i.e. Duanzhuang Sub-district (5.127 m^2/person), Wangling Sub-district (5.119 m^2/person), and Heping Sub-district (2.684 m^2/person).

The average supply of green space in 453 residential areas is 12.66 m^2/person, and the highest supply value is Jincaijiayuan Community, which is 88.2 m^2/person; there are 144 residential areas with the average number of green space supply exceeding 14.6 m^2/person, accounting for 31.7% of the total. As many as 68.3% of the residential areas did not meet the 14.6 m^2/person standard stipulated in the 13th Five-Year Plan of China, of which 181 residential areas were less than 5.5 m^2/person, accounting for 40.0% of the total. Most of these residential areas are located in the north and southeast of Quanshan District, with few comprehensive parks around.

The fairness of green space distribution in Quanshan District is higher in the South than in the north, and higher in the West than in the East. The Gini coefficient of the spatial distribution of green space in the 453 residential areas in Quanshan District has reached 0.3659, which is close to the warning line, indicating that the fairness of the spatial distribution of green space in the research area should be paid enough attention. The Gini coefficient of two sub-districts exceeds 0.4, i.e., Huohua Sub-district (0.4203) and Zhaishan Sub-district (0.4041). It shows that the distribution of urban green space in these two sub-districts is unfair. The Gini coefficient of Taishan, Jinshan and Hubin Sub-district is 0.1632, 0.2154 and 0.2349, respectively. Meanwhile, the per capita green space area is also high, indicating that the supply of green space resources in these three sub-districts is sufficient and the distribution is fair. The Gini coefficient of Heping, Wangling and Duanzhuang Sub-district is 0.1854, 0.3567 and 0.3783, respectively, but the per capita green space area is less than 5.5 m^2, showing the phenomenon of low per capita green space but high fairness.

In order to eliminate the service blind area of urban green space in Quanshan District, the spatial layout of green space is optimized in three stages, i.e., short term (3-5 years), medium term (8-10 years) and long term (15 years). In the three stages, the urban green space area was increased by 87.730 hm^2, 100.024 hm^2 and 56.038 hm^2 respectively, improving the supply of green space in 128 residential areas, accounting for 28% of the total, among which 39 residential areas reached the standard of 14.6 m^2/person. The per capita supply of 453 residential areas has increased from 12.660 m^2 to 15.451 m^2, and the per capita supply of green space in seven sub-districts has reached the standard. The residential-level Gini coefficient was reduced by 31.7% to 0.2499, meanwhile the Gini coefficient of each sub-district decreased by about 7% on average, and the value was less than 0.4.

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