Assessing the Disparity between Supply and Demand of Green Spaces by Elderlies based on GIS – Taking Wuhan, China as an Example

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Abstract. Urban green space (UGS) are crucial sites for providing ecosystem services. Given the context of population aging and the national initiative of Health China, it is urgently needed to identify service blind areas, and scientifically select green space construction regions through the coordination of supply and demand evaluation. Focusing on the central area of Wuhan, this paper calculated the supply and potential demand of the elderly for UGS by GIS network analysis, kernel density, and Thiessen polygon, identified the service blind areas of green spaces by overlay analysis, and used the location-allocation model to purposefully supplement green space. The results indicated that under the assessment of walking accessibility, the supply of green space is good. The blind areas of urban green space supply are 20.54%, but the accessibility range within a short period needs to be improved. The elderly show a multi-core layout mode influenced by environmental and historical factors. There is a mismatch between the demand for green space by the elderly and its actual layout. 12.50% of the areas have insufficient supply, this study optimized the urban spatial layout of the 7 UGS in these areas, of which 3 are in Hongshan District, 2 in Qingshan District, and 2 in Jiangan District. The research findings can give references to improving the supply and demand balance of urban green space for the elderly, addressing the current imbalance and inadequacy in green space provision.

Keywords: urban green space; environmental justice; population aging; nature-based solutions.

1. Introduction

Over the last few decades, cities have experienced significant growth as economic, cultural, and social hubs due to the acceleration of global urbanization. This rapid development has brought up concerns regarding the residents' quality of life [1], with issues including the selection of venues for relaxation and unwinding having commanded substantial attention from scholars worldwide. Urban green space encompasses urban territory predominantly featuring natural and artificial vegetation, which incorporates the land utilized for greening within the urban construction land, as well as the area beyond the construction land, offering a better greening environment for residents' leisure activities, urban ecology, and landscape[2]. UGS serve as essential places providing ecosystem services to residents, in addition to playing a vital role in the well-being of residents[3].

Population aging has emerged as an irreversible trend within Chinese society. In response to the challenges posed by this demographic shift, China has implemented various policies and initiatives, including the Outline of the Program for *Health China 2030* and *the National Fitness Plan (2021-2025)* at mitigating the impact of aging on social development. In this context, research on elderly-oriented urban green space planning has become an essential topic. Research on UGS, incorporating demographic characteristics, is mainly conducted into two types, one is for the entire user as a whole, and the other is for the specific demographic group. Yet, there is a lack of detailed quantitative analysis studying the supply and demand of urban green space for the elder group[4,5].

The points mentioned above show that planning UGS for the elderly is an urgent task. To date, scholars have devoted considerable attention to research on urban green space resources. In general, scholars have conducted thorough research on the supply and demand of UGS among residents, but integrating research on green space with planning practices and applying advanced GIS technologies still needs further study in the realm of green space construction[6]. Indeed, many

existing researches have emphasized the layout of UGS, concentrating on aspects such as accessibility and equity, although these studies can identify ongoing obstacles based on current distribution characteristics and offer constructive suggestions, the consideration for optimizing layouts remains limited to qualitative analysis and policy recommendation, quantitative proposals for particular site selection based on scientific methodologies are scarce, resulting in study conclusions cannot be directly applied to planning practices. On the other hand, considering the government's limited finances, it is not feasible to construct numerous green spaces in the short term, how to accurately determine the construction areas is a major challenge in layout planning.

As a key national urban center, Wuhan is facing significant challenges due to the increasing depth and accelerating pace of population aging. This demographic shift presents critical obstacles to social progress and governance, highlighting the issue as a major concern at multiple levels. Considering the above, this research utilizes the built-up area of Wuhan as a case study and analyzes the supply and demand of the elderly for urban green space. In specific, this study utilizes network analysis, kernel density, and Thiessen polygon to measure the supply and demand of UGS, and adopts overlay analysis to measure the supply-demand matching characteristics of UGS. Furthermore, this study identifies supplemental green spaces in areas with insufficient supply utilizing the location-allocation model, which can provide a reference for constructing the system of the types of urban green space designed for the elderly, urban planning, and green space management.

2. Study area

Wuhan, served as the the capital city of Hubei Province, is the largest city in central China. In the urban built-up areas of Wuhan, the green coverage rate is 43.09%, the green space rate is 40.05%, and the per capita green space area is 14.99 m2[7]. In recent times, the notion of ecological livability has experienced considerable momentum. In 2018, Wuhan issued the Implementation Plan for the Establishment of a National Ecological Garden City in Wuhan, taking the creation of an ecological garden city as an opportunity to comprehensively carry out the management of the ecological environment, vigorously expand UGS, improve the level of garden greening, and expedite the modernization of harmonious coexistence between human beings and nature[8]. Wuhan is among the Chinese cities that entered the aging society relatively early[9]. According to the United Nations, an aging society is one where people aged 60 and above make up more than 10% of the total population[10]. By the end of 2022, the city's old population, aged 60 and older, reached 1.9895 million, comprising 21.30% of the overall population,[11] indicating that Wuhan has stepped into the deep aging society. Therefore, this study opts for the built-up area of Wuhan as the subject area (Figure 1), covering an area of approximately 955.15 km2.

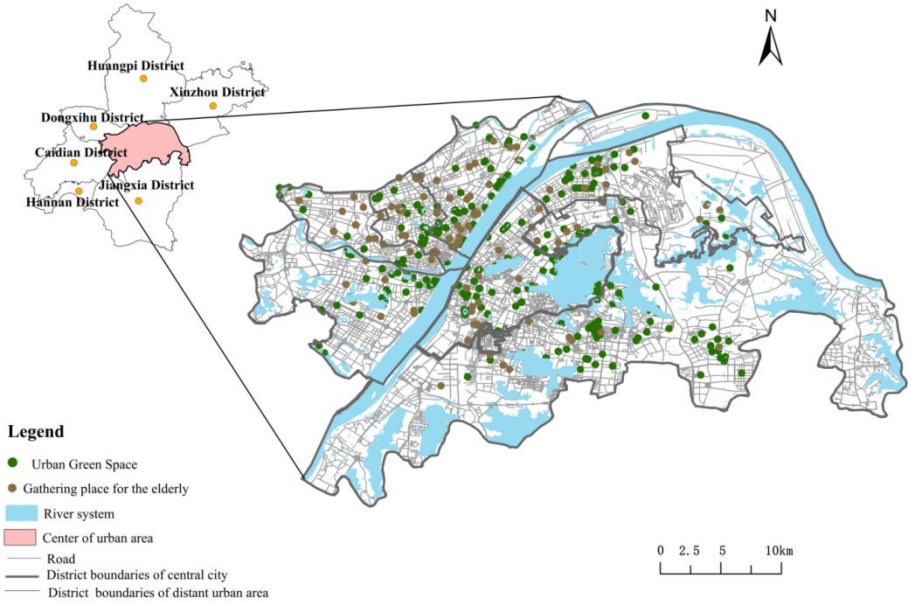

Fig.1 Spatial distribution of urban green space and the elderly

3. Data source and methods

3.1 Data and preprocessing

The data used in the study include land use data, urban green space data, elderly distribution data, road data, and Wuhan administrative boundary data. The land use data was obtained by downloading global land use maps from Sentinel-2 satellite imagery with a resolution of 10 meters from ERSI (https://livingatlas.arcgis.com/landcoverexplorer/) and then masking and reclassifying the data. The urban green space and elderly distribution POI data were sourced from the Guihuayun website (http://guihuayun.com/), of which 267 UGS were collated from parks, lawns, and greening centers, and 112 elderly gathering places were collated from nursing homes, senior apartments, and senior service centers. Road data were downloaded from OpenStreetMap for Chinese road data and then underwent topological processing. Administrative boundary data for Wuhan was obtained from the Aliyun Visualization Map Platform.

3.2 Research Methods

3.2.1 Evaluating urban green space supply based on network analysis

The accessibility of green spaces reflects their social service value and can be measured in terms of a service radius, which represents the area that can be covered within a certain distance from the starting point of the green space[12]. The network analyses were conducted utilizing the ArcGIS, the service area was established with the UGS as origins using appropriate walking times and distances. Walking distance and time were designated as costs, calculated as the horizontal distance between two points via the network[13]. The walking speed for elderly pedestrians was established at 1 m/s[14] based on a literature review, and service areas of 5, 10, and 15 minutes were utilized for walking duration. Accordingly, the supply accessibility of urban green space can be divided into four levels. Taking 267 UGS as starting points, make the service map of urban green space range under time cost of three grades (0~5min, 5~10min, 10~15min)[15]. Then, overlay the points of the elderly gathering place on the current map of urban green space service areas to calculate the ratio of the supply of UGS covering the elderly gathering place.

3.2.2 Evaluating urban green space demand based on kernel density and Thiessen polygon

POI data can indicate the intensity of crowd activity in the form of point elements[16], areas with high intensity of crowd activity have a high demand for green space. Kernel density analysis is a widely used spatial analysis method that calculates the weighted average density of observed data within a specified search area around each point, thus generating a spatial distribution map of the observed objects[17]. This study assesses the extent of demand among the elderly for UGS by calculating the service pressure of green spaces and the kernel density of the elderly. The steps include: 1) Based on the coverage of all the elderly POI points in the study area, use the Thiessen polygon to establish the service range of UGS and represent the area of UGS in terms of their service range. The service pressure of UGS can be calculated using the formula 1; 2) Use ArcGIS to produce the kernel density distribution map of the elderly agglomeration sites; 3) The results of the calculations of the kernel density of the elderly and the pressure on urban green space service pressure are categorized into five categories, respectively, adopting the natural breaks method.; 4) Under the assumption of equal weights for demand assessment factors, use the raster math to multiply each factor's influence by its respective weight and then sum them (The formula 2); 5) Apply the natural breaks method to reclassify the average weighted demand analysis results into low, intermediate, and high demand areas.

$$SP_{urban\ green\ space} = \frac{N}{A} \#(1)$$

$$E = 0.5 \times KD_{elderly} + 0.5 \times SP_{urban\ green\ space} \#(2)$$

Where $SP_{\text{urban green space}}$ is the service pressure of the UGS; N is the number of points of interest of the elderly within the service range of UGS; A is the area of UGS; KDelderly is the kernel density of the elderly; E is the result of the comprehensive evaluation of the demand analysis of the elderly. The larger the E is, the higher the demand of the elderly for UGS.

3.2.3 Supply and demand analysis of urban green space and layout optimization

By employing reclassification and overlay analysis, the study area was separated into nine different types, according to the outcomes of the urban green space supply capacity and demand analysis, high supply and high demand, high supply and intermediate demand, high supply and low demand, intermediate supply and high demand, intermediate supply and intermediate demand, intermediate supply and low demand, low supply and high demand, low supply and intermediate demand, and low supply and low demand[18]. According to previous studies[19,20] , these nine types of areas are further categorized into five supply-demand matching types, namely, shared areas (intermediate supply and intermediate demand), clustering areas (high supply and high demand), balanced areas (low supply and low demand), under-supplied areas (low supply and intermediate demand, low supply and high demand, intermediate supply and high demand), under-demand Areas (high supply and intermediate demand, high supply and low demand, intermediate supply and low demand). To eliminate the disparity between supply and demand, in the process of constructing supplemental urban green space, considering the distribution of types characterized by supply-demand matching of UGS, areas with under-supplied green spaces are targeted, and at the same time combined with the type of land use, which is suitable for constructing a new urban green space in regions consisting of grassland (excluding the existing green space) and bare ground, to get the potential scope of the construction of urban green space. The location-allocation model of GIS software was used to designate potential sites for urban green space construction in the built-up area of Wuhan. Elderly gathering places and the 150m x 150m lattice arrays were respectively treated as request points and candidate sites, given the problem of capital investment for green space construction, it is not possible to construct multiple green spaces at the same time to cover all of the elderly, the study utilized the algorithm for minimizing the number of facility points within the location-allocation model, aiming to minimize the number of selected facility points while maximizing coverage, and the impedance interruption was set to a 15-minute walking time of the elderly. Ultimately, the model yielded potential construction locations for urban green space.

4. Results

4.1 Analysis of the supply of UGS

The overall supply condition of UGS is good, but there are still relatively few UGS accessible to the elderly within a short walking time. Among them, most areas fall within the 15-minute walking range except for the eastern part of the built-up area. However, in short-distance walking within 5 minutes, only 37.50% of the areas are covered, suggesting that there is room for enhancement in this regard.

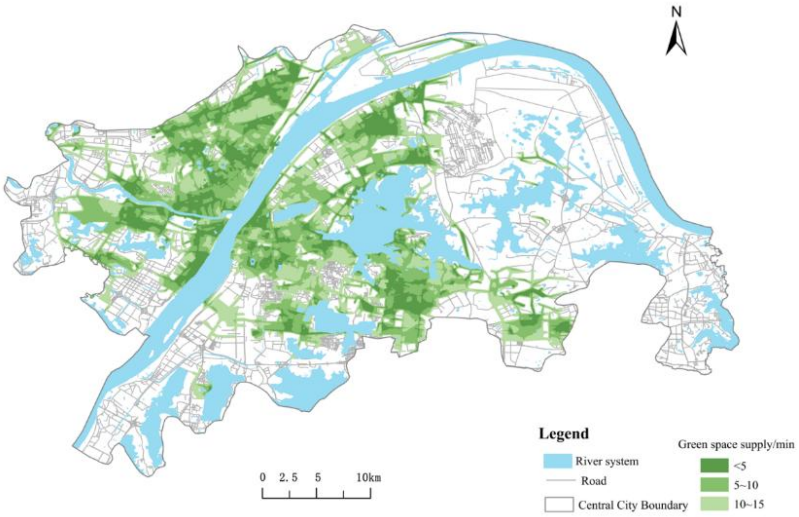

Fig.2 The walking accessibility of urban green space

In terms of spatial distribution (Figure 2), in the built-up area of Wuhan, senior pedestrians have a relatively easy time going to the UGS. The distribution pattern exists whereby regions adjacent to rivers and lakes demonstrate greater accessibility in comparison to inland areas, also, the western region exhibits a higher degree of accessibility in contrast to the eastern region. Areas with favorable accessibility are primarily situated along the banks of the Yangtze River, around the Donghu Lake, Liangzi Lake, and other water areas, conversely, areas with poor accessibility are found in the southeastern part of Hongshan District and the eastern part of Qingshan District, particularly in the Baowu Steel area. Meanwhile, the eastern part belongs to the suburbs with lower development levels, and green spaces have not yet been constructed there.

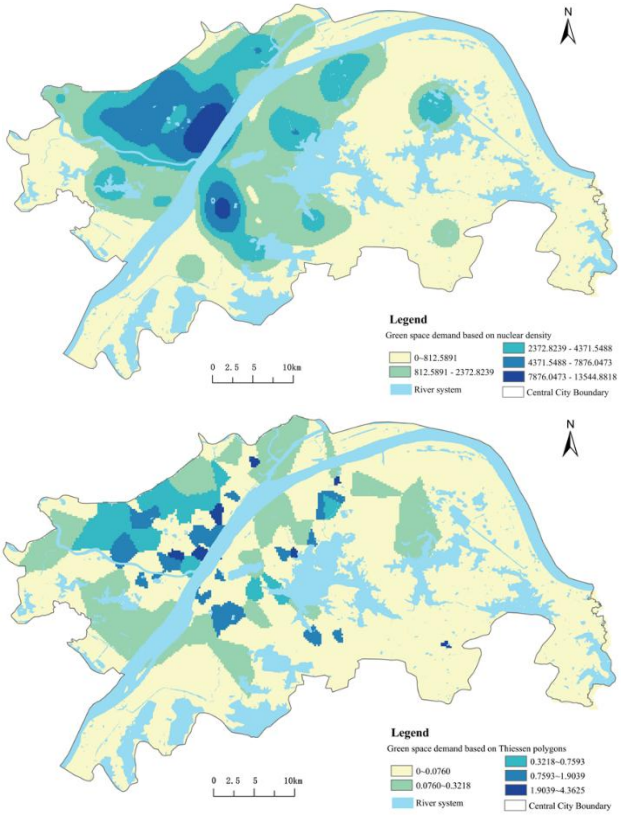

Fig.3 The kernel density of the elderly
Fig.4 The service pressure of the green space

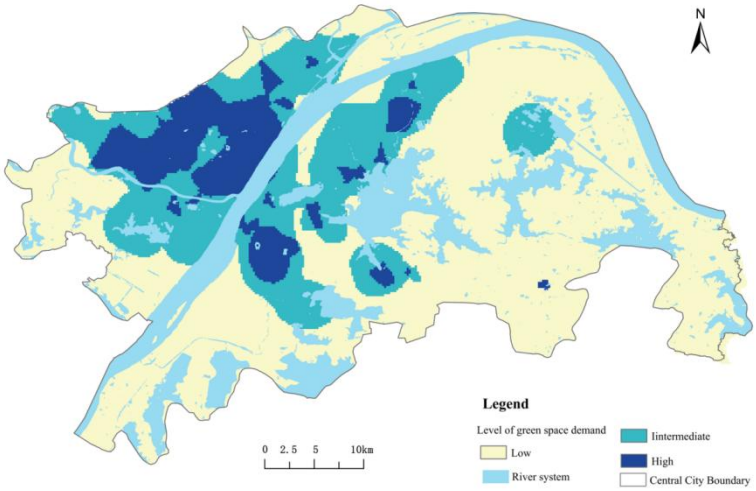

Fig. 5 The elderly's demand for urban green space

Regarding spatial distribution, the demand for UGS exhibits a pattern of high demand in the northwest and low demand in the southeast, as shown in Figure 5, the high-demand areas for UGS are predominantly located in the central part of Qiaokou District, the southern part of Jiang'an District, the southwestern part of Wuchang District, and the northern and southern parts of Jianghan District, the areas with intermediate demand are primarily located in the northern part of Jiang'an District, the eastern part of Hankou District, the northern part of Jianghan District, and the northern part of Wuchang District, while the eastern parts of Hongshan District and Qingshan District are generally low-demand areas.

4.2 Characterization of matching supply and demand for urban green space

The coordination relationship between the supply and demand for urban green space is shown in Figure 6, and the corresponding matching levels and area percentages reveal an imbalance in the supply and demand of urban green space in the study area, with distinct characteristics of spatial

heterogeneity. Figure 6 shows that 57.72% of the study area is classified as balanced urban green space, mostly situated in the eastern and southern regions of Hongshan District. The shared area and the clustering area are roughly equivalent, each making up around 3.75% and 4.40% of the total. The under-supplied and under-demanded areas indicate matching levels of mismatch between supply and demand, with ratios of 12.50% and 21.64% respectively, and are distributed in block-like patterns along the Yangtze River and the lake area, primarily located in Qiaokou, Jiangan, Jianghan, and Wuchang District.

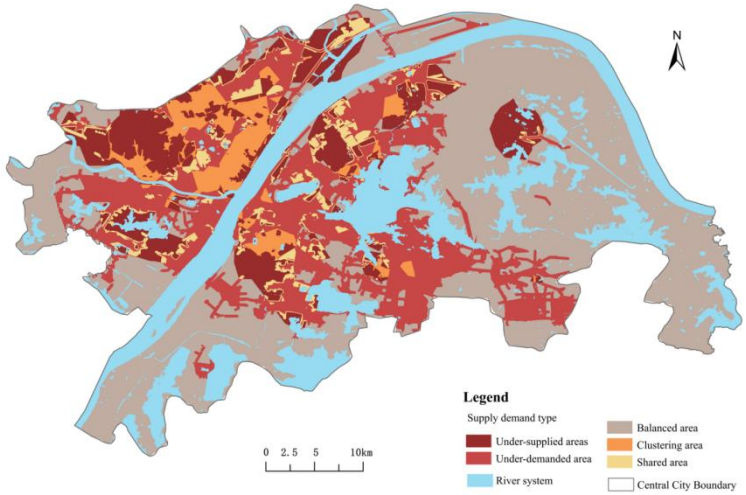

Fig. 6 Coordination relationship between supply and demand

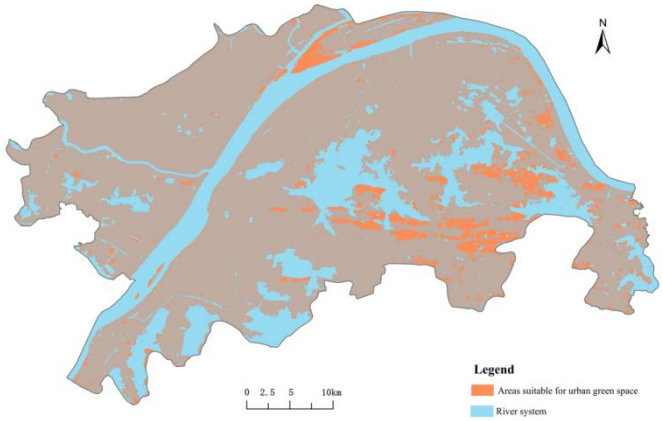

Fig. 7 Potential green space construction area

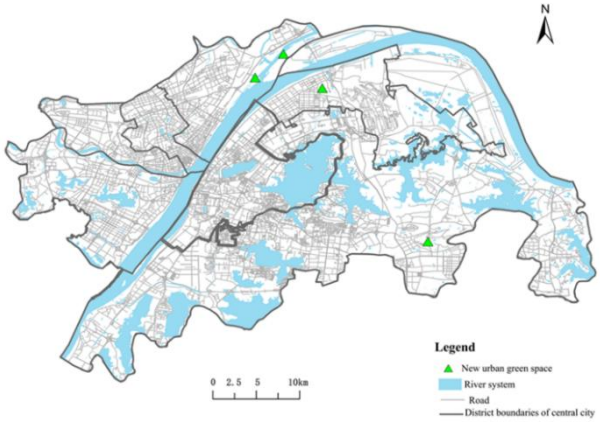

Fig. 8 Potential construction sites

Drawing from the measurement of supply accessibility and demand estimation results, areas with insufficient supply were identified. Combined with land use types, undeveloped land was selected to determine the potential construction areas of UGS (Figure 7). Large-scale built-up areas have restricted the potential scope for new UGS. The potential construction scope of UGS exhibits a

fragmented distribution, mainly at the junction of Jiang'an District and Qingshan District along the Yangtze River, as well as in the southern parts of Donghu Lake, Yanxi Lake, and Yandong Lake. Figure 8 displays the study results of potential urban green space construction sites in the city, identifying a total of 7 feasible construction points. Overall, the distribution of potential urban green space construction sites is relatively sporadic. Among them, 3 new urban green areas are planned for Hongshan District, 2 for Qingshan District, and 2 for Jiang'an District, no urban green areas are proposed in Wuchang District and Jianghan District. The primary cause of this phenomenon is the high level of urban development in these areas, resulting in limited suitable locations for new UGS, but the existing green spaces can be optimized to improve their service conditions and alleviate the imbalance between supply and demand.

5. Discussion

This study integrates the social dimension of the aging population with the spatial dimension of UGS, focusing on and catering to the demand of the elderly when investigating the demand for UGS to ensure the elderly receive more social attention, particularly regarding their health status, quality of life, and social participation. Such measures not only make up for the shortcomings of the study of the importance of the demand for urban green space in the life of the elderly, but also promote the comprehensive development of society and enable the people of the whole society can share the fruits of modernization. Conventional approach to evaluating the accessibility of green spaces relies on buffer radii surrounding service centers to compute coverage rates[21]. This method only considers the distance factor, failing to comprehensively consider the impact of actual environmental factors such as transportation networks and road quality on green space accessibility, thereby affecting the scientificity and accuracy of green space planning and management. In contrast, this paper utilizes the accessibility time of the elderly as the principal condition for judging the spatial supply of UGS, and the network analysis method relying on road network infrastructure can evaluate the supply situation of UGS more objectively. Furthermore, this study takes POI data as a guide and covers various GIS analysis methods such as network analysis, kernel density, Thiessen polygons, and visualization to quantitatively explore the demand for UGS in the built-up area of Wuhan, and the acquisition of all data is open source with scalability and dynamic updating, providing valuable contributions for big data-driven green space system planning.

This study analyzes the alignment between urban green space and the distribution of the elderly from both supply and demand angles, and proposes a better urban green space configuration. In previous studies, qualitative judgments and non-spatial evaluations were mostly used. Traditional approaches to green space planning emphasize the principle of uniformity, whereas, in reality, the layout of the UGS should be considered in conjunction with the distribution of the population and transportation accessibility[22]. However, indicators such as per capita green space area, green space ratio, and green coverage rate do not adequately reflect the spatial layout of UGS, and these metrics solely analyze green spaces from a supply-side perspective, neglecting the demands of the population and the balanced distribution of green space resources across the entire spatial area. From the standpoint of supply-demand balance, this study evaluates the current status of urban green space construction through the indicators of accessibility, kernel density, and service pressure, which can not only identify the problems in the layout of urban green space more accurately, but also propose recommendations for optimizing the urban green space system more efficiently. Compared to traditional subjective site selection processes, the minimization facility location-allocation model can effectively improve the coverage of urban rhythmic services.

There are still a few restrictions in this study. First, the supply of UGS is not just determined by their coverage range, it is also closely associated with the scale and completeness of green space facilities, the service content within the green spaces, and the landscape elements of the green spaces themselves, these factors lead to differences in the attractiveness of each green space to the elderly, and the elderly may not necessarily choose the nearest green space, instead, they might opt

for the urban green space that is farther away, but with a stronger appeal. Moreover, the study only considers the accessibility assessment of the elderly under pedestrian traffic, leaving out the choice and combination of other modes of transportation (bus, subway, etc.); Finally, this study evaluated the demands of the elderly through Points of Interest (POI), which only included nursing homes, senior apartments, and senior service centers, and there may be some missed venues. In the future, the scope of POIs can be further expanded by including, but not limited to, community fitness facilities, medical institutions, and parks to assess the needs of the elderly more comprehensively.

6. Conclusion

From the standpoint of supply-demand balance between UGS and the elderly, this study constructs indicators for the supply capacity of urban green space and the demand of the elderly in the built-up area of Wuhan based on multi-source data such as urban green space, POI points of the elderly, and land use, and portrays the accessibility of and potential demand for UGS, and proposes corresponding optimization strategies for the spatial layout of UGS with the help of a location-allocation model utilizing the superimposed comparative analysis of the two. These discoveries represent valuable information for urban planning and enhancing the quality of life of the elderly. The main conclusions are as follows: 1) The blind areas for urban green space supply are 20.54%. The accessibility of urban green space in the built-up area of Wuhan based on walking travel mode decreased from the river to the inland circle. The supply capacity of UGS is relatively good, but the scope of services within a short period of walking accessibility still needs to be improved; 2) The calculation of the elderly's demand for UGS reveals a structure of high demand in the northwest and low demand in the southeast. The elderly are mainly concentrated in Jianghan, Qiaokou, Jiang'an, and the southwest part of Wuchang District; 3) The spatial imbalance between urban green space supply and the demand from the elderly is quite pronounced, with different types of supply-demand matches occurring in various areas. Approximately 12.50% of the areas exhibit insufficient supply. Through optimization of urban green space quantity combined with land use conditions, this study proposes to add potential construction of UGS 7, with 3 in the Hongshan District, 2 in the Qingshan District, and 2 in the Jiangshang District.

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