Understanding Accessibility of Health and Fitness with Big Data Techniques: Facility Visualization in Shanghai with Multi-Source Data

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ABSTRACT

Accessibility of health and fitness services is important for the rehabilitation in the post-epidemic era. The emergence of multi-source data offers new and timely approaches to understanding health and fitness facilities (HFFs) in cities. Taking Shanghai as an example, this paper obtained the HFFs dataset through platforms such as GaoDe, and crawled data were accurately classified into Street level, District level and Municipal level. Based on spatial data mining, the spatial differentiation of current HFFs was understand. The analysis through Kernel Density Estimation (KDE) and the Multi-mode Two-step Floating Catchment Area Method (M2SFCA) indicates that HFFs basically meet the needs of most residents in the city within their service scope. The Lorentz curve results shows that top 20% community residents enjoy up to 73.66% of HFFs. This shows that there is a large difference in HFF accessibility among community residents. This article presents a visualization example of spatial computing in understanding health accessibility and can provide a timely reference for policy making.

Keywords: Visualization; Health; Fitness; M2SFCA; Accessibility; Multi-source data.

INTRODUCTION

1.1 Health and Fitness Facilities (HFFs)

With the development of the social economy, the concept and needs of residents' lives are changing, and health and fitness have become a necessary demand and high-frequency choice for people. On October 28, 2016, the General Office of the State Council issued *the Guiding Opinions on Accelerating the Development of the Fitness Industry*, which put forward the requirements for improving the health and fitness infrastructure network and planning and building supporting fitness facilities in urban residential areas to form a 15-minute fitness circle in the city (Wang et al., 2019). On December 20, 2017, the Ministry of Land and Resources formulated and announced *the Land Control Indicators for Urban Public Stadiums*. It can be seen that the supporting construction of cultural fitness facilities has been raised from the level of government and demands the attention of the whole society. With the improvement of scientific and technological standards, the living structure, mode, and survival behavior of urban residents have also undergone major changes. As an important part of health activities in society at the present, sports are an important way for urban residents to maintain physical and mental health, relax and relieve stress (Bil et al., 2021). People are increasingly aware of the benefits of participating in sports activities. At the same time, with the outbreak of the COVID-19 epidemic in 2019, the construction of 'square cabin hospitals' in HFFs is also an innovative move for human beings to respond to public health emergencies (Liu et al., 2020). It breaks through people's understanding that HFFs are only used for competitions, fitness, entertainment, exhibitions, and other activities, and has triggered a rethinking of the function of HFFs in responding to sudden public crises. In addition, health and fitness facilities (HFFs), such as HFFs, play an important role in maintaining the healthy lifestyle of residents, which has been emphasized by previous scholars (Xie et al., 2020, Zhang et al., 2022, Wang et al., 2018, Bykov et al., 2019 & Qiu et al., 2022). Therefore, strengthening the supply side of health and fitness and promoting the fair construction is an important topic for diagnosing the accessibility of health.

1.2 Space equity and HFFs

Driven by the humanistic trend, two general trends, human culture, and socialization, appeared in the geoscientology of the west in the 1970s. *The Social Justice and City* by Harvey combines spatial elements with Marx's theory, pointing out that urban space is not only the carrier of urban social and economic activities but also determines the distribution mode of various resources and interests in cities (Cardoso et al., 2007 & Zhu et al., 2021). Some emerging planning theories and practices pay great attention to the injustice in the social and the inequality of opportunities in urban development, emphasizing that urban planning as a public policy should be based on promoting social equity and social justice. For example, the new *Greater London Space Master Plan* in 2004 implemented the concept of social equity and several measures to achieve equitable accessibility (Chiu. R.L., 2004). China's urban planning has also experienced a trend from purely technical norms to public policy. In *the Measures for the Preparation of Urban Planning* issued in 2005, it was pointed out that urban planning is one of the important public policies of the government to regulate urban public policies, guide urban development and construction, safeguard social equity, and protect the public safety and public interests (Abramson. D.B., 2006). It has pointed out that urban planning should reflect the concept of spatial equity, pay more attention to how to provide public resources for urban residents, and ensure the effective supply and rational distribution of urban public resources so that residents of different social and economic backgrounds can obtain relatively equal public services (Qian et al., 2021). Therefore, reflecting the concept of spatial equity is an inevitable requirement for urban planning as a public policy (Bai et al., 2021).

From the perspective of Shanghai as a whole, with the spread of the city and the suburbanization of the population, the spatial distribution of HFFs is uneven, which is mainly manifested in two aspects: on the one hand, it reflects "intensive inside the city and sparse outside the city" in the overall space, forming an unbalanced distribution of three circles inside, middle and outside. On the other hand, most foreign HFFs are based on the layout of the life circle. At the beginning of the construction, HFFs in Shanghai were mainly large-scale sports facilities, mainly serving sports events, ignoring the public services and efficient spatial layout, which eventually result in the uneven distribution. The imbalance in the supply is also manifested in heavy quantity and quality, attaching importance to new facilities, and the functional excavation and transformation of existing HFFs is not obvious.

1.3 HFFs in Shanghai, China

Due to the high socio-economic development in developed countries, people have a higher discretionary income, and the understanding of health and fitness is also more in-depth and widespread. Although China's economy has developed rapidly in the past 30 years of reforming and opening up, its per capita income is not high, the level of discretionary income is low, and the demand for improving the quality of life has not been fully demonstrated. In particular, the investment in health and fitness at a higher demand level but still at a beginning stage. Consumers' psychology tends to be conservative, the confidence is not strong, and the change in consumption concepts is slow. This situation interacts with the current high price level and other factors, inhibits the desire of residents, especially middle- and low-income people, to consume on health and fitness, and reduces the consumption demand. On the other hand, local government departments have been paying too much attention to economic development, neglecting health and people's livelihood to a certain extent, and lacking strategic thinking and long-term planning. Therefore, although Shanghai is economically developed, due to its dense population and some residents' insufficient awareness of the importance of the health and fitness facilities and services have not been paid attention to.

1.4 Computational Techniques and Big Data in understanding HFFs

In 2013, the Shanghai Municipal Government proposed to build a '30min healthy life circle'. By 2015, it has built a circular distribution of 30min life circles with convenient facilities and perfect functions covering urban and rural areas and put forward guiding opinions according to their temporal and spatial characteristics. With the development of big data, for the reason that the collection of POI data is relatively easy, with a wide range of applications and strong operability, which can improve the spatial accuracy of urban research, the domestic literature using POI data for urban research showed explosive growth in 2017, and its rise led to the revolution of urban research (Wei et al., 2022, Wu et al., 2021 & Jun et al., 2021). However, it is rarely used to consider the equity of HFFs. In Shanghai, an area with a high level of urbanization and development in China, the development of HFFs is relatively perfect, and the agglomeration of different types of HFFs is high. Therefore, the paper hopes to take Shanghai as an example to discuss the evolution of the spatial pattern and equity of HFFs in the past 10 years through POI data.

METHODS

2.1 Research regions and data

Public HFFs refer to the venues, equipment, buildings, environment, and related facilities that can be used by citizens to carry out daily physical exercise and activities in the city for meeting the demands for activities and fitness, which do not include open public places such as citizens' squares, parks, and lakesides. This paper takes provincial (city), district, and street-level urban HFFs as the research object. To accurately collect the data, the research classified HFF data crawled by Python from the GaoDe geographic platform as follows: Street-level: elderly activity centers, community fitness squares, community children's playgrounds, community gyms, and commercial HFFs, basketball courts, community swimming pools; District level HFFs: all kinds of special HFFs, such as badminton halls, table tennis halls, volleyball halls, bowling alleys, boxing halls, wrestling halls, etc.; Municipal HFFs: HFFs that can host more than 5000 people, and the detailed statistics are shown in Table 1.

The spatial scope of data collection in this study is mainly the administrative jurisdiction of 16 districts and counties in Shanghai, with the community as the smallest spatial unit. The residential population data studied came from the 2021 population statistics of Shanghai, and the data on HFFs at all levels mainly came from the 2021 network POI data of Gaode Map, the 2021 Google satellite aerial map, *the 2021 Shanghai Facilities Statistics Table* and other data.

Table 1. HFF classification and statistics.

Rank	Quantity	Proportion of quantity	Total area	Proportion of area	Time Threshold
a. Street level	81	54.36	925082.5	27.54	15
b. District level	44	29.53	900373	26.80	30
c. Municipal level	24	16.11	1533641.2	45.66	30

2.2 Research methods

2.2.1 Spatial autocorrelation method

Spatial autocorrelation analysis studies the correlation between spatial samples and their surrounding samples, reflecting the distribution characteristics of spatial samples, which are mainly divided into global autocorrelation and local autocorrelation (Qiu et al., 2021 & Li et al., 2022). In this paper, the local Moran's I is selected as the measurement index to observe the spatial distribution characteristics of HFFs in Guangzhou. The formula is as follows:

$$I = \sum W_{IJ}\, Z_i Z_j \tag{1}$$

In the formula: Z_i and Z_j are the standardized value of the per capita gym area. The local Moran index can divide regions into four different types, namely, high-high agglomeration (H-H), high-low agglomeration (H-L), low-aggregation (L-L), and low-high-aggregation (L-H).

2.2.2 Kernel Density Estimation (KDE)

Kernel density estimation (KDE) plays an important role in the visualization of point data, and has been widely used in the study of understanding spatial evolution, such as infrastructure and innovation space (Yang et al., 2019, Xu et al., 2022 & Liu et al., 2020). Based on the density calculation of discrete points within a certain window range, the density evolution diagram of the spatial connection of the HFFs can be obtained by KDE with adaptive bandwidth. In this way, the agglomeration area of different types of HFFs points was explored. With such POI density value calculation, the optimal search radius based on the density range will be determined as follows:

$$\omega(x) = \sum_{i=1}^{n} \frac{1}{\pi r^2} \varphi\left(\frac{d_{zy}}{s}\right) \tag{2}$$

Where: $\omega(x)$ is the KDE value of the point element at x, r is the radius of the search area, φ is the distance weight, d_{zy} is the distance between the point element z and the point element y, and n is the total number of POI.

2.2.3 Multi-mode Two-step Floating Catchment Area Method (M2SFCA)

The Multi-mode Two-step Floating Catchment Area Method (M2SFCA) is adopted to access the accessibility of HFFs. Specially, it will be evaluated by considering facilities' supply and population demand. The higher convenience of using HFFs a resident can get, the higher the accessibility the area is. However, the traditional 2SFCA based on ArcGIS network cannot reflect the situation under multiple travel modes. In particular, it is worth noting that M2SFCA is more able to examine the accessibility of public transport and complex road networks. Therefore, this paper adopts the Multi-mode Two-step Floating Catchment Area Method (M2SFCA) and measures the accessibility of Shanghai multi-mode HFFs. The three travel modes selected are walking, cycling and bus travel (Ni et al., 2019 & Paul et al., 2019). The specific calculation process is as follows:

First of all, calculate the travel time and the community population of arriving the Class I HFFs in three modes: walking (M1), cycling (M2), and public transportation (M3). Among them, the priority levels for residents to choose the travel mode are walking, cycling, and public transportation respectively. That is, if residents can reach this type of HFF by walking within the predetermined time threshold, only the travel time and community population of the HFF in the walking mode are calculated; otherwise, the travel time and community population of such HFFs by cycling are calculated; finally, it is to calculate the travel time to such HFFs by public transportation and the community population. The calculation process is as follows:

Supply-demand ratio of the HFF needs to be calculated first, which is called the service capacity:

$$R_j = \frac{S_j}{\sum_{j \in t_{ij}(M_1) \leqslant t_0(c)} r_{iM_1} \times G\left(t_{ij}(M_1), t_0(c)\right) + \sum_{j \in t_{ij}(M_2) \leqslant t_0(c)} r_{iM_2} \times G\left(t_{ij}(M_2), t_0(c)\right) + \sum_{j \in t_{ij}(M_3) \leqslant t_0(c)} r_{iM_3} \times G\left(t_{ij}(M_3), t_0(c)\right)} \tag{3}$$

In the formula, R_j is the serviceability of HFFs j; S_j is the area of HFFs j; and r_{iM_1}, r_{iM_2}, and r_{iM_3} are the numbers of people who reach HFFs j through walking, cycling, and public transportation within the time threshold respectively; and $t_{ij}(M_1)$, $t_{ij}(M_2)$ and $t_{ij}(M_3)$ are the travel time from the community to HFFs in walking, cycling, and public transportation travel mode respectively; $t_0(c)$ is the time threshold of category c-level HFFs (see Table 1); G is based on the time attenuation coefficient of Gaussian function, and the calculation formula under walking mode (M_1) is as follows:

$$G\left(t_{ij}(M_1), t_0(c)\right) = \begin{cases} \frac{e^{-(1/2)\times\left(t_{ij}(M_1)/t_0(c)\right)^2} - e^{-(1/2)}}{1-e^{-(1/2)}}, & \text{if } t_{ij}(M_1) \leqslant t_0(c) \\ 0, & \text{if } t_{ij}(M_1) > t_0(c) \end{cases} \quad (4)$$

The calculation formula for the time attenuation coefficient of public transportation and car travel mode is the same as above.

Secondly, it is needed to calculate the sum of the supply and demand ratio of HFFs. It is the accessibility of communities to reach HFFs within the time threshold:

$$A_i = \sum_{j\in t_{ij}(M_1)\leqslant t_0(c)} R_j \times G\left(t_{ij}(M_1), t_0(c)\right) + \sum_{j\in t_{ij}(M_2)\leqslant t_0(c)} R_j \times G\left(t_{ij}(M_2), t_0(c)\right) + \sum_{j\in t_{ij}(M_3)\leqslant t_0(c)} R_j \times G\left(t_{ij}(M_3), t_0(c)\right) \quad (5)$$

Among which, A_i is the accessibility of HFFs in the community i. The value represents the accessibility level of HFFs in the community.

2.2.4 HFF equity measurement

Gini coefficient and Lorentz curve analysis are often used as quantitative indicators for the evaluation of social equity performance (Chen et al., 2019). They were originally proposed by the American statistician called Lorentz to explore the issue of income distribution equity. And the income distribution based on the connotation of social equity is essentially similar to public resource allocation, so this method has been widely used in the field of environmental equity in recent years. To reflect the fair character bureau of the resource distribution of urban HFF facilities in Shanghai, this paper builds a equity model of HFFs based on the Gini coefficient, measuring the differences in the accessibility of HFFs in various districts and streets, and visualizing and analyzing their spatial patterns. The formula for calculating the model is as follows:

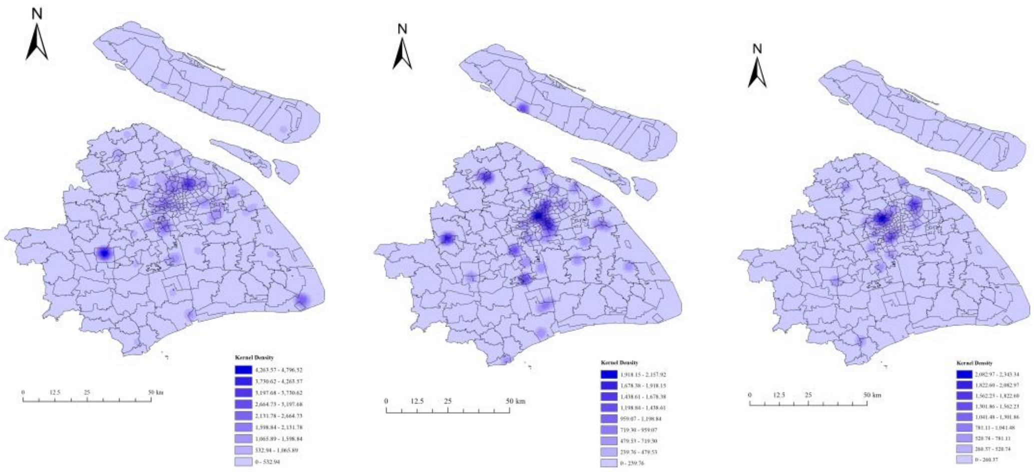
$$GE_u = 1 - \sum_{k=1}^{n} (P_k - P_{k-1})\,(C_k + C_{k-1}) \quad (6)$$

$$C_k = \frac{\sum_{i=1}^{k} A_i r_i}{\sum_{i=1}^{n} A_i r_i} \quad (7)$$

Where, GE_u is the venue equity index of the geographical unit u (district or street); n is the total number of communities in the geographic unit u; k is the k^{th} community after the accessibility of venues in the community is ranked from the smallest to largest, $k = 1,2\ldots n$; A_i is the accessibility value of venues in the community i; r_i is the population of the community i; C_k is the cumulative ratio of accessibility to venues k from community 1 multiplied by community population, C_0 =0, C_n =1; P_k is the cumulative proportion of community population from community 1 to community k, P_0 = 0, P_n = 1. According to the mathematical meaning of Gini coefficient, when $GE \leq 0.2$, it indicates that the space allocation of venue resources is highly average; When $0.2 < GE \leq 0.3$, it indicates that the space allocation of venue resources is relatively equal. When $0.3 < GE \leq 0.4$, it indicates that the space allocation of venue resources is reasonable; When $0.4 < GE \leq 0.5$, it means that the space allocation gap of venue resources is large; If the GE is greater than 0.5, it means that there is a huge gap in the space allocation of venue resources, and there is a serious inequity.

RESULTS

3.1 KDE Analysis



(a) Street level (b) District level (c) Municipal level

Figure 1. Kernel density of HFFs in Shanghai.

The analysis of the Kernel density of three different types of HFFs in Shanghai (see Figure 1) shows that street-level HFFs have the highest Kernel density, followed by district-level HFFs, and the lowest are city-level HFFs. However, the three types of HFFs overlap to a certain extent in the agglomeration of Kernel density, especially the distribution density (H-H) distribution of street-level and district-level HFFs in the district of Xuhui, and Hongkou in Shanghai. From the analysis map of the Kernel density of district-level HFFs (see Figure 1b), it can be found that the distribution of district-level HFFs is mainly concentrated around various campuses in central areas such as Hongkou, Xuhui and Changning in Shanghai, as well as the high-end communities nearby. The distribution of district-level or even street-level HFFs in other regions has not formed a high aggregation, and the state of which is much more scattered (see Figure 1a). From the analysis of the Kernel density of municipal HFFs (see Figure 1c), it can be seen that the overall distribution of Shanghai is relatively average and the number is relatively small. Except for the Shanghai HFF, the Workers' HFF, and the Yuanshen Sports Center, the distribution of HFF facilities in other regions is relatively scattered.

(a) Street level (b) District level (c) Municipal level

Figure 2. Accessibility of HFFs at all levels in Shanghai.

3.2 Multi-scale Analysis

The Geometrical Interval is available to spatially visualize the accessibility of muti-scale HFFs in Shanghai. It can be seen in Figure 2 that the multi-scale HFF in the same area has a large space difference. Among them, the areas with low accessibility are mainly located around the Fengxian District, Jinshan District, and the southern Songjiang District. This is likely due to the high population density of the community in the central urban area. Therefore, the HFFs configured by the community is mainly small-scale community-level and street-level HFFs to meet the needs of the high-density population. At the same time, the overall accessibility of the community HFFs is generally high. On the contrary, for relatively small peripheral urban areas such as Jiangshan District, eastern Fengxian District, and southern Songjiang District, the accessibility of multi-scale HFFs is generally low and far smaller than the central area. Among them, the spatial pattern of the accessibility of district and municipal HFFs is consistent with the spatial distribution of HFFs at all levels, indicating that fewer HFF resources are available in these areas (Figure 2a and 2b**)**. And from the accessibility of municipal HFFs (Figure 2c), the proportion of areas with high accessibility is much larger than that of other types of HFFs, indicating that municipal HFFs basically meet the needs of most residents in the city within their service scope.

Exploring Shanghai's multi-scale HFFs is not possible, there is no possibility of the availability of the vacant room, the main text is the first of the Moran index (Moran's I) for the future of the text. The results show that the Moran's I index is 0.039, the Z score is 3.933, and the P value is less than 0.0001, indicating that the Shanghai multi-scale-travel mode HFF accessibility index has significant spatial agglomeration and spatial autocorrelation. Through local autocorrelation tools, the spatial agglomeration characteristics of different regions are analyzed. The results show that communities with low accessibility of HFFs (low-low) are concentrated in peripheral urban areas such as Jinshan District, Fengxian District, southern Songjiang District, and western Qingpu District, while communities with high accessibility of HFFs (high-high) are concentrated in Xuhui District, Changning District, Hongkou District, and Eastern Putuo District. From the perspective of spatial correlation (Figure 3, Figure 4), the area with high spatial correlation in low-low value clustering is mainly located in Jinshan

District, while the spatial aggregation degree of high-high-value clustering is the highest on the west side of the Bund, followed by the central part of Pudong New Area.

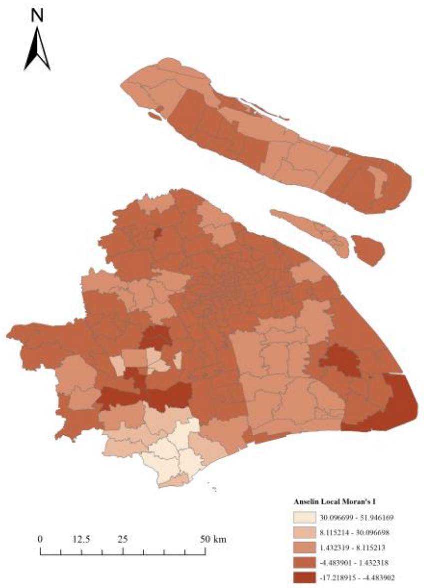


Figure 3. Local Moran Index of accessibility.

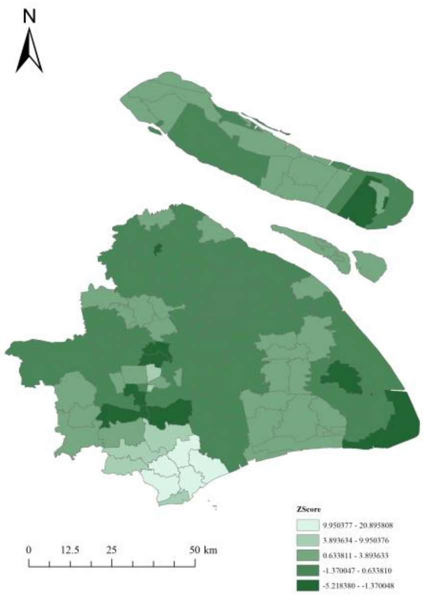


Figure 4. Z-valued pattern.

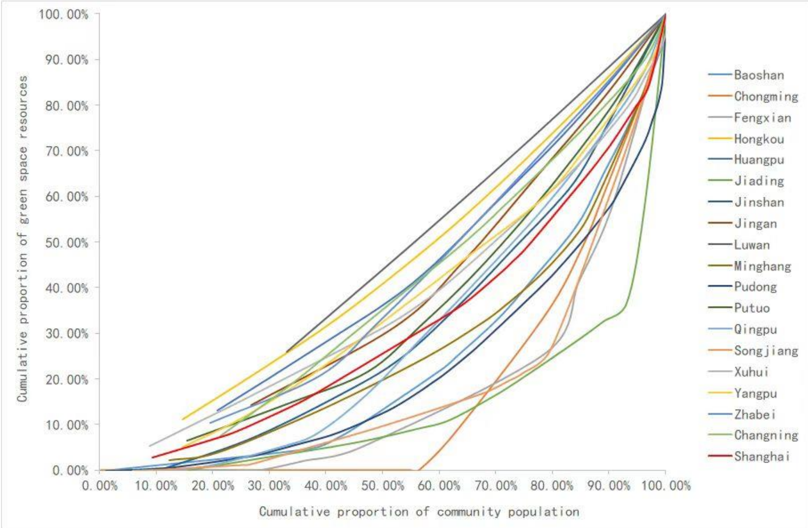


Figure 5. Lorentz curve of multi-scale HFF resource allocation in Shanghai.

3.3 Differences in allocation of HFFs

Overall, the spatial distribution of HFFs in Shanghai is seriously unequal (the HFF equity index is less than 0.1). Through the Lorentz curve, the distribution of Shanghai multi-scale-multi- travel mode HFF accessibility between regions is analyzed (Figure 5). The greater the curvature of the curve, the more unfair the allocation of HFF resources is. For community residents with fewer HFFs, the top 10% of residents enjoy only about 0.75% of HFFs, and the top 20% of residents enjoy only about 2.16% of HFFs; for community residents with more HFFs, the top 10 % of residents enjoy about 51.21% of HFFs, and the top 20% enjoy up to 73.66% of HFFs. This shows that there is a large difference in the distribution of HFFs among Shanghai community residents.

CONCLUSION

This paper takes 16 urban, municipal, district, and street HFFs in Shanghai as the research object, analyzes their spatial layout and service level, and introduces a two-step mobile search method and the Lorentz curve to comprehensively evaluate the social equity performance of HFFs, and uses spatial autocorrelation to further analyze the spatial patterns and differences of social equity performance. The research results show that there are shortcomings in the planning and construction of HFFs at all levels in Shanghai, and there are significant differences in the distribution of their service levels. The higher the level of facilities, the more they are concentrated in urban centers. The overall service level shows the characteristics of "center-to-edge attenuation", which is affected by urban topographic elements, spatial patterns, and stages of development. Based on the cumulative population, the equity score is lower than 0.01, reflecting the wide gap in the distribution of resources for HFFs in Shanghai, which is highly polarized. The vast majority of the resources of urban HFFs are occupied by a very small resident population, which is caused by the accumulation of both facilities and population in urban centers. To this end, we should constantly strengthen the planning and construction of HFFs in the peri-urban areas, and promote the organic evacuation of the urban population and the regional balance between supply and demand, so that more facilities and resources can be effectively used by more residents. Finally, the distribution of resources of HFFs in Shanghai is uneven, and the specific spatial representation is externally low, internal high, and medium-balanced. At the same time, its configuration presents the characteristics of central agglomeration.

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