Scientific Research Publishing

Advances in Physical Education, 2025, 15(2), 159-176
https://www.scirp.org/journal/ape
ISSN Online: 2164-0408
ISSN Print: 2164-0386

Investigation into the Accessibility and Equity of Public Fitness Facilities: A Case Study Based on Wuhan, China

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How to cite this paper: Chen, P., & Zhao, P. X. (2025). Investigation into the Accessibility and Equity of Public Fitness Facilities: A Case Study Based on Wuhan, China. *Advances in Physical Education, 15,* 159-176.
https://doi.org/10.4236/ape.2025.152012

Received: February 27, 2025
Accepted: March 23, 2025
Published: March 26, 2025

Abstract

People have more equitable access to public fitness facilities, is crucial for improving public health and maintaining social stability. Using the Gaussian-Based Two-Step Floating Catchment Area, the accessibility of fitness facilities in Wuhan was accurately measured, and the equity of the distribution of fitness facilities in Wuhan was analyzed. The study found: There is a clear pattern of differentiation in the accessibility of fitness facilities for all residents in Wuhan, with differences existing between the central urban areas and the peripheral urban areas, as well as among different jurisdictions; there is a certain degree of inequity in the layout of fitness facilities for all residents in Wuhan, leading to spatial deprivation for groups with lower socio-economic status, characterized by poorer accessibility in neighborhoods with lower housing prices, higher plot ratios, and a greater number of residents. Two policy suggestions for the future planning and layout of fitness facilities for all residents in Wuhan are as follows: first, to improve the distribution structure and enhance accessibility by rational planning and construction; and second, to focus on vulnerable groups and coordinate the supply-demand relationship to promote the equity of fitness facilities.

Keywords

Public Fitness Facilities, Equity, Accessibility, Gaussian Two-Step Floating Catchment Area Method, Geodetector

1. Introduction

Promoting the equalization of people's rights and interests is a key measure to ensure social harmony and stability. Public service facilities are basic urban

buildings and equipment that concern people's livelihood and connect their hearts. They are an important guarantee for meeting the basic needs of survival and development of the people, as well as a strong pillar for satisfying the higher-level needs of the people. The "Outline of the 14th Five-Year Plan (2021-2025) for National Economic and Social Development and Vision 2035 of the People's Republic of China" proposes to continuously improve the level of basic public services equalization. Advancing the equalization of basic public service facilities is an important means to solidify and ensure the fundamental needs of people's livelihood, as well as a powerful measure to meet the multilevel, direct, and diversified needs of the public. As one of the key areas of public service facilities, national fitness facilities serve as the material basis for promoting the widespread participation in physical fitness activities. They are also essential for establishing a higher-level public service system for national fitness. The construction of these facilities should start by serving the people, be guided by fairness and justice, and continuously meet the growing needs of the people for a better life. In recent years, the supply of national fitness facilities has been increasing, laying a solid foundation, creating favorable conditions, and providing important guarantees for building a higher-level public service system for national fitness. With the acceleration of urbanization, the surge in urban population, and people's living spaces shifting from low-density and spacious to high-density, compact, and smaller areas (Zhang & Guo, 2020), the shortage and uneven distribution of national fitness facilities have become increasingly prominent. Statistical data show that by the end of 2022, China's per capita sports area was 2.62 square meters (General Administration of Sport of China, 2022), which is far from the 16 m^2 per capita in the United States and 19 m^2 per capita in Japan (Yang & Su, 2023). Additionally, most of China's sports facilities are located east of the Hu Huanyong Line (Heihe-Tengchong Line), with fewer sports facilities in the western regions (You & Ren, 2023). It is evident that the increasing demand for fitness facilities and the shortage and uneven distribution of such facilities are becoming increasingly tense. To effectively resolve this contradiction, it is necessary to implement the concept of modern urban construction comprehensively, accurately, and in its entirety. There is also a need to vigorously accelerate the construction of public service facilities for national fitness and to keep pace with the times by utilizing modern statistical measurement and data analysis methods to guide construction planning. In summary, guiding the planning of national fitness facilities through comprehensive statistical theories and spatial analysis methods in geography not only is a powerful measure to enhance the rationality of decision-making in the planning and construction of national fitness facilities but also addresses the accessibility and equity issues of community fitness facilities in reality. It is also an important way to reduce the shortage and uneven distribution of national fitness facilities, and an urgent task to allow the results of modernization to benefit all people more fairly and extensively. This has significant theoretical and practical implications.

2. Overview of Related Research

Accessibility was first defined by Hansen as "the potential for spatial interaction and the capacity to overcome spatial separation (Hansen, 1959)", often used to indicate the ease with which one area can be reached from another (Talen, 2016). The accessibility of public services for national fitness refers to the ease or difficulty residents experience in reaching national fitness facilities from their community. Currently, research applying geographical spatial analysis methods to the distribution of sports facilities is very limited (Tang & Zhang, 2022). Studies on the accessibility of public services for national fitness primarily employ the cost of travel method (Jin & Yao, 2017) and GIS network analysis (Wu et al., 2022). These approaches are limited to evaluating the supply side and rarely address the demand side (Wei & Wang, 2019), failing to consider residents' willingness to engage in physical activities. The data on national fitness facilities used in these studies are static and homogeneous, unable to measure the facilities' capacity through Euclidean distance or network distance, types of facilities, and facility parameters. These factors lead to biased results and weak guidance in evaluating the accessibility of national fitness facilities. The research incorporates the Gaussian decay coefficient to dynamically assess the relationship between spatial distance and residents' willingness to act, and uses the A map Web API to collect area data of sports service facilities, evaluating their capacity to reduce the bias in accessibility results, thereby arriving at more objective conclusions.

The equity of public service facilities distribution has always been an important topic of concern for scholars and decision-makers (Zeng & Xiang, 2017), with studies on the equity of public service facilities available to different regions and groups beginning earlier in Western countries (Mavoa et al., 2012). With the development of China's socio-economy, phenomena of social stratification and spatial differentiation have appeared in some Chinese cities (Zhang, 2017), and the field of Geographic Information System (GIS) research is very broad (Ma & Jiang, 2015). Based on a perspective of social equity, studies using GIS to focus on public service facilities have emerged (Zhan & Zhang, 2019), some emphasizing urban-rural differences, spatial distance, and the convenience of transportation conditions (Hu & Lu, 2021), while others focus on group differences, directing attention to vulnerable groups such as disabled and elderly people (Xu et al., 2019). However, research on the convenience of access to public service facilities for residents with different socio-economic conditions is scarce, particularly in the area of national fitness facilities. Thus, studying the equity of access convenience to national fitness facilities among different socio-economic groups is a practical measure to fill the current research gap and an important initiative in advocating for the equitable distribution of social resources. Therefore, scientifically measuring the accessibility and equity of national fitness facilities is a useful guide for planning and constructing public service facilities for national fitness, a powerful approach to building healthy cities, and a practical pathway to more equitably benefiting all people with the achievements of modernization.

3. Overview of the Study Area

Situated in the central region of China, "Jingchu Land" Hubei is the only province where the Yangtze River flows for over a thousand kilometers. It serves as the central support province for the economically coordinated and market-integrated Yangtze River Economic Belt and acts as a major transportation hub, featuring dual hubs for passenger and freight aviation and a "cross-shaped" high-speed rail network extending in all directions, making it a crossroads for nine provinces. Hubei is a crucial economic center bridging China's eastern and western provinces and a key transportation nexus for both domestic and international dual circulation strategies. Wuhan, the capital of Hubei, blends natural beauty with cultural richness. Located in the central-eastern part of Hubei, Wuhan plays a significant role in leading the province and supporting the central region. It has been at the forefront of embracing market economy reforms and serves as a pioneer in achieving modernization benefits for all people in the new era. As an essential component of modernization efforts, public fitness facilities are fundamental infrastructures that directly meet the growing fitness demands of the people and are key to realizing the vision of a Healthy China and a strong sports nation. In response, the Wuhan Municipal Government has introduced a series of development planning policies to provide comprehensive guidance for the planning and construction of public fitness facilities in Wuhan, thus ensuring a solid foundation for building a higher-level public fitness service system in the city. Therefore, focusing on Wuhan as the study area for researching the accessibility and equity of public fitness facilities represents a crucial step towards addressing the issues of supply shortage and uneven distribution in economically developed, transportation-convenient major cities. It is an important means to construct a higher-level public fitness service system in line with current trends and a determined practice to extend the benefits of modernization to all people.

4. Research Data and Preprocessing

4.1. National Fitness Facilities Data

The study used Google imagery data to organize the data on public service facilities for national fitness in Wuhan City into areas of interest (AOI), which can be divided into 8 categories: basketball courts, football (soccer) fields, badminton courts, table tennis courts, water sports, billiards, equestrian, and comprehensive sports halls, totaling 1559 facilities. Among them, there are 94 basketball courts with an average area of 1756.54 m^2, such as Spalding Basketball Club, Maikewei Ballroom, Cloud Basketball Court, etc.; 16 football fields with an average area of 18425.40 m^2, such as Panhai International Football Field, Yunlong Road Football Center, EP Football Theme Park, etc.; 55 badminton courts with an average area of 988.15 m^2, such as Xuanfei Badminton Hall, Berminton Badminton Hall, Lianao Badminton Hall, etc.

4.2. Community and Population Data

The community division data for the study area comes from high-resolution Gaofen-

2 imagery vectorized in ArcGIS, and the population data comes from 100 m precision population grid data published by WorldPop (http://www.worldpop.org.uk/). The community division data and population data were imported into ArcGIS 10.8. First, the population grid data was clipped using a mask of the study area to obtain the population grid data within the study area; then, the population grid was summarized by community to obtain the population number of each community within the study area (Figure 1).

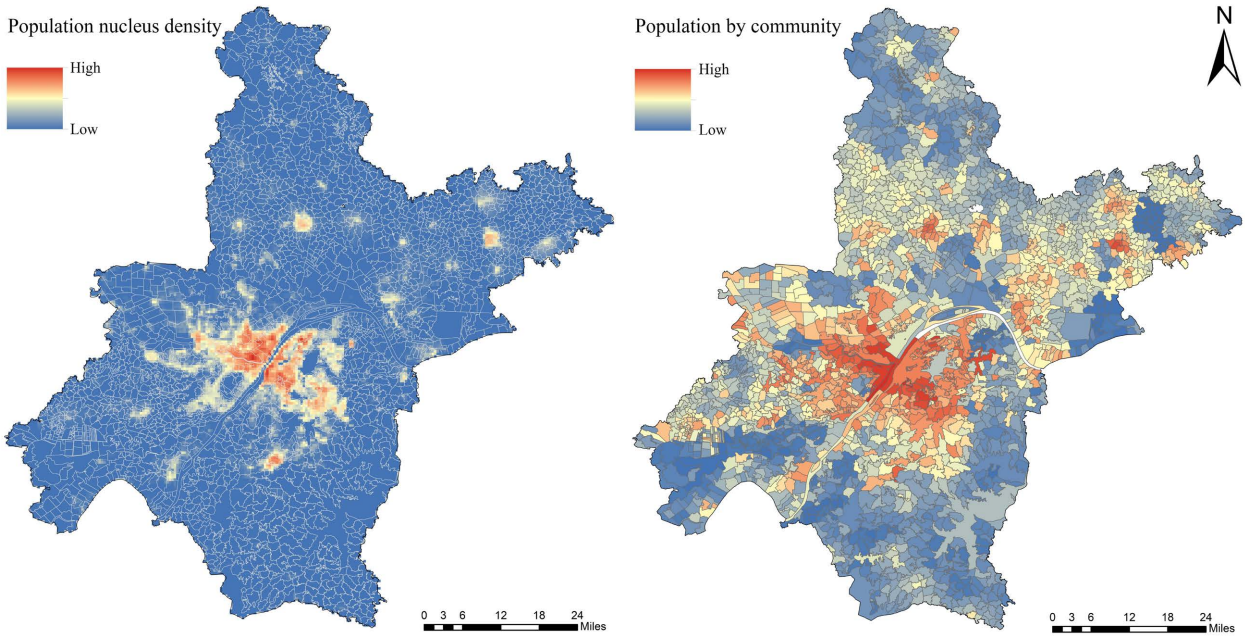

Figure 1. Population Kernel density and sub-district population numbers in Wuhan City. Maps were created using ArcGIS10.8 (Environmental Systems Research Institute, USA. https://www.esri.com/).

4.3. Socio-Economic Data

The socio-economic data comes from the community data of Wuhan city provided by Lianjia (https://sz.lianjia.com/) and Anjuke Real Estate Website (https://nc.anjuke.com), with the acquisition date being October 15, 2023. The fields include community name, latitude and longitude, unit house price, greenery rate, floor area ratio, and the number of households, among other indicators. Subsequently, missing data were filled in by linear interpolation to ensure the consistency and completeness of the data. Then, the socio-economic data was linked to the community SHP data using the community name as the linking field.

5. Research Framework and Methods

5.1. Research Framework

The study is divided into three parts: firstly, supply and demand analysis based on Euclidean distance and data on facilities, communities, and populations; secondly, accessibility analysis for different modes of travel using the Gaussian two-step floating catchment area (2SFCA) method; and thirdly, equity analysis for resi-

dents in different socio-economic environments using the geographical detector approach (Figure 2). In the supply and demand analysis, various national fitness facilities are considered as supply points and community centroids as demand points. A neighborhood analysis tool in ArcGIS 10.8 generates a proximity table, and the OD (Origin-Destination) cost matrix is calculated based on Euclidean distance to describe the spatial distance costs between different start and end points (Le & Wang, 2021). In the accessibility analysis, circles with radii representing walking, cycling, and driving distances of 15 minutes are drawn as thresholds. The OD cost matrix is then clipped to these boundaries to summarize the supply capabilities of all national fitness facilities within the reach of community demand points, thereby determining the supply accessibility, i.e., the accessibility of communities to national fitness facilities. In the equity analysis, four factors—community floor area ratio, greenery rate, number of households, and average community housing price—are classified into five categories using the natural break (Jenks) method. Then, the accessibility values Ai calculated in the second step are used as the dependent variable for factor and interaction detection. The results help analyze the differences in accessibility to national fitness facilities for residents under different socio-economic conditions, thus measuring the equity of access to national fitness facility services among residents with different economic statuses.

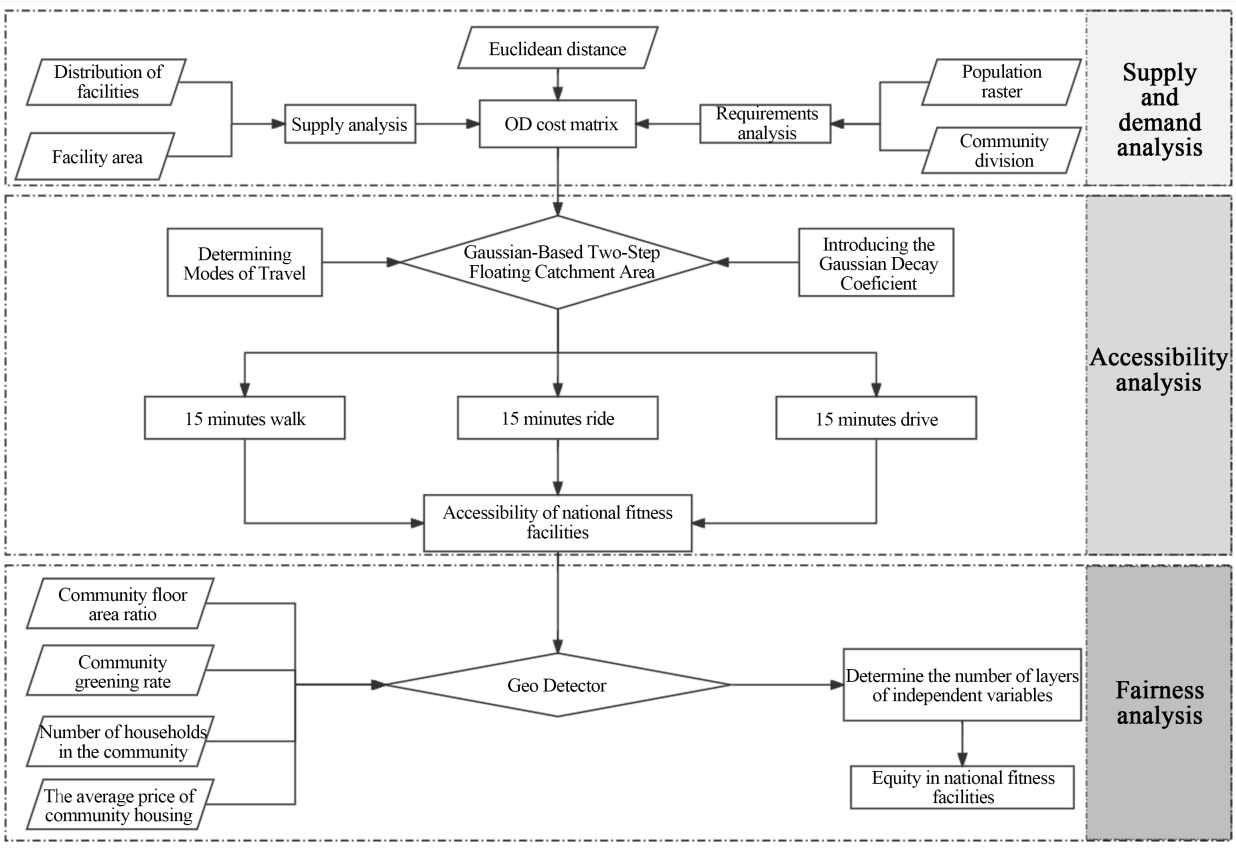

Figure 2. Research framework for accessibility and equity of public fitness facilities. Framework was created by ProcessOn.

5.2. Research Methods

5.2.1. Gaussian-Based Two-Step Floating Catchment Area Method

The Gaussian-Based Two-Step Floating Catchment Area (2SFCA) method takes into account factors such as population size, service facility area, and differences in travel resistance to quantitatively analyze the match and service reasonableness between populations and public service facilities. Population data is used to measure demand, with communities serving as the statistical unit for population data; the area of service facilities measures supply. Generally, the area of public sports service facilities is positively correlated with supply volume. Travel resistance is dynamically measured by the Gaussian decay coefficient combined with the actual Euclidean distance between supply and demand points. The specific steps of the 2SFCA are as follows:

In the first step, centroids of national fitness facilities are extracted as supply points *j*. Circles with radii of distance d_0, representing walking, cycling, and driving distances of 15 minutes, are established as search domains. All population numbers within the search domains are summarized. The Gaussian decay coefficient is used to assign weights according to spatial decay rules, and the weighted populations are then aggregated to each national fitness facility supply point to measure the demand covered by this supply point. The area S_j of the national fitness facility supply points is used to measure the supply volume of the supply points. Finally, the supply-demand ratio R_j is calculated to measure the supply capability of the national fitness facilities:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}<d_0\}} G(d_{ij})D_k}$$

In the formula, D_k represents the population of the demand unit *k*, d_{kj} is the Euclidean distance between demand point *k* and supply point *j*, and d_0 is the search domain, which corresponds to areas accessible by walking, cycling, and driving for 15 minutes. S_j is the area of the national fitness facility, and $G(d_{ij})$ is the Gaussian decay coefficient considering spatial friction. The calculation formula is:

$$G\left(d_{ij}\right) = \frac{\mathrm{e}^{-\frac{1}{2}\times\left(\frac{d_{ij}}{d_0}\right)^2} - \mathrm{e}^{-\frac{1}{2}}}{1-\mathrm{e}^{-\frac{1}{2}}}$$

In the second step, taking the centroid *i* of the community as the demand point, and establishing search domains with radii of distance d_0, which correspond to areas accessible by walking, cycling, and driving for 15 minutes, locate all national fitness facilities *j* within the region. Assign spatial decay weights to the supply capability R_j of each national fitness facility within the search domain, and then aggregate them to the demand point to obtain the accessibility value A_i for the demand point. The formula is:

$$A_i = \sum_{j\in\{d<d_0\}} G\left(d_{ij}\right)R_j$$

Establish a spatial connection between the accessibility values A_i of each com-

munity calculated through Equation (3) and the community FID, then use a symbology system to represent the accessibility values A_i of each community with gradient colors. The classification method chosen is the natural breaks classification method (Jenks).

5.2.2. Geographic Detector

The Geographic Detector (Geographic Detector) is a spatial data analysis statistical model that judges the spatial distribution similarity of two variables from the perspective of spatial stratified heterogeneity (Wang et al., 2010). Its principle is that if an independent variable has an effect on a dependent variable, then the spatial distributions of the independent variable and the dependent variable should tend to be consistent (Wang & Xu, 2017). The Geographic Detector can detect the explanatory power of the independent variables on the dependent variable, i.e., the degree of influence of the independent variables on the dependent variable. It is widely applied in research fields related to geographic space, such as the distribution of public service facilities (Jiang et al., 2021), urban land use change (Li & Liu, 2018), and residents' livability satisfaction (Zhan & Zhang, 2015). The specific expression is:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2, SST = N\sigma^2$$

In formula (4), $h = 1, \cdots, L$ represents the stratification (Strata) of the dependent variable Y or the independent variable X, with the study classifying the independent variable into five categories using the natural breaks classification method (Jenks). N_h and N represent the number of units in stratum h and the entire area, respectively, while σ^2 hand σ^2 denote the variance of the dependent variable Y within stratum h and the entire area, respectively. SSW is the sum of within-stratum variances (Within Sum of Squares), and SST is the total variance across the entire area (Total Sum of Squares). The value of q ranges from [0,1], and since the study only classifies the independent variable X, it does not consider the spatial variation characteristics of the dependent variable Y. Therefore, a larger q value indicates a stronger explanatory power of the independent variable X on the dependent variable Y, and vice versa. Specifically, a q value of 1 means that the independent variable X completely controls the spatial distribution of the dependent variable Y, while a q value of 0 means that the spatial distribution of the dependent variable Y is unrelated to the independent variable X. At the same time, interaction detection evaluates whether the combined effects of different independent variables on the dependent variable enhance or weaken the explanatory power, or whether these factors influence the dependent variable independently. The test results are represented by color bands, which, from left to right, indicate nonlinear weakening by a single factor, nonlinear weakening by multiple factors,

enhancement by two factors, independence, and nonlinear enhancement.

6. National Fitness Facilities Accessibility Analysis

Firstly, using the spatial analysis-proximity table feature in ArcGIS10.8, an OD (Origin-Destination) cost matrix for reaching community from national fitness facilities is generated, with thresholds set as "15-minute walking distance", "15-minute cycling distance", and "15-minute driving distance". Then, the accessibility values Ai calculated through formulas (1) - (3) in section 2.2.1 are connected to the study area communities using the community FID (File Identifier Descriptor) as the linkage basis. Subsequently, the natural breaks classification method (Jenks) is used to color-code the accessibility values. After visualization, the spatial distribution characteristics of national fitness facilities' accessibility by mode of transportation are obtained (**Figure 3**). Lastly, the accessibility values for six districts of Wuhan City, including Hongshan District, Xinzhou District, and Jiangxia District, are extracted individually. Origin 2021 is utilized to plot histograms and fitting curves of the accessibility values Ai to observe the distribution of national fitness facilities' accessibility values (**Figure 4**).

Research shows: Accessibility to public fitness facilities in urban centers is significantly better than in peripheral urban areas. Considering the spatial differences in accessibility to public fitness facilities in Wuhan City from a geographical perspective, it's evident that areas with higher accessibility, whether by walking, cycling, or driving, are concentrated in the central urban area of Wuhan, while the accessibility in peripheral urban areas is poor. This indicates that residents in peripheral urban areas have more difficulty accessing public fitness facilities compared to those in central urban areas, a result that has been corroborated by existing studies. There are two reasons: First, there are fewer public fitness facilities in peripheral urban areas. The population in urban peripheral areas is relatively sparse, leading to a lower demand for public fitness facilities, and thus, the planning and construction of public fitness facilities in these areas are given lower priority. Second, there is a lack of geographical information data. It is more challenging to enter data from urban peripheral areas, especially those surrounding mountains and natural parks, into electronic maps (Guo et al., 2020), resulting in a scarcity of public fitness facility data when collecting AOI data using platforms like A map, making it impossible to calculate a significant number of peripheral urban areas that public fitness facilities could serve. This results in data gaps and the phenomenon of "blank areas" in the accessibility of public fitness facilities in peripheral urban areas. However, data collection was conducted through multithreading across different jurisdictions without systematic differences between the search processes of each jurisdiction, making the overall search results unbiased and the relative results of data analysis robust.

The spatial layout of public fitness facilities is a key factor affecting their accessibility. From the perspective of the spatial layout of public fitness facilities, the study found that the accessibility values around public fitness facilities radiate outward in a "ripple" pattern (**Figure 3**), meaning the closer to the fitness facilities,

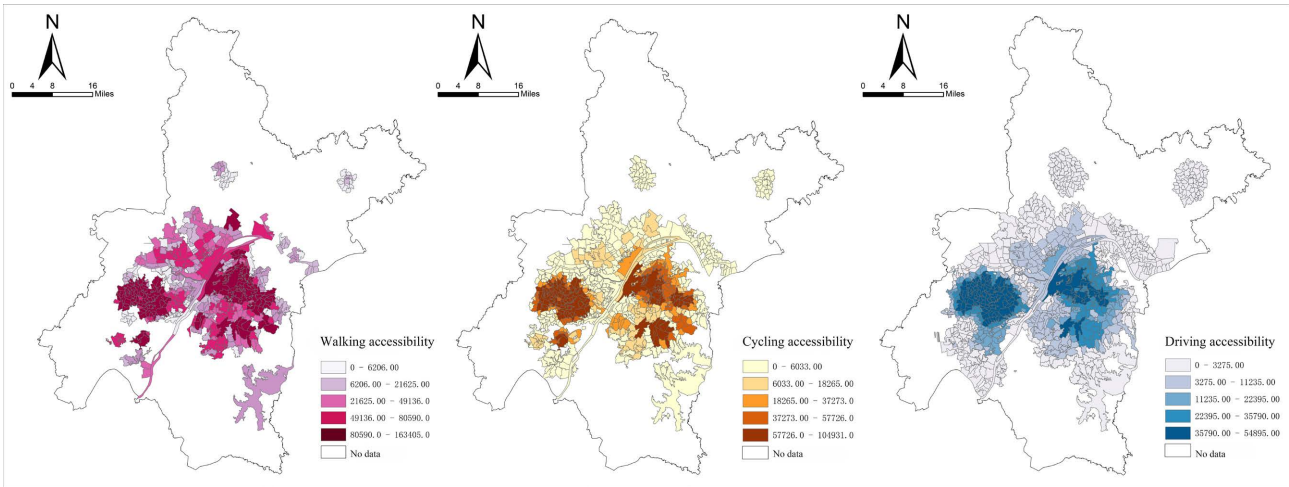

Figure 3. Spatial characteristics of accessibility to public fitness facilities by travel modes. Maps were created using ArcGIS10.8 (Environmental Systems Research Institute, USA. https://www.esri.com/).

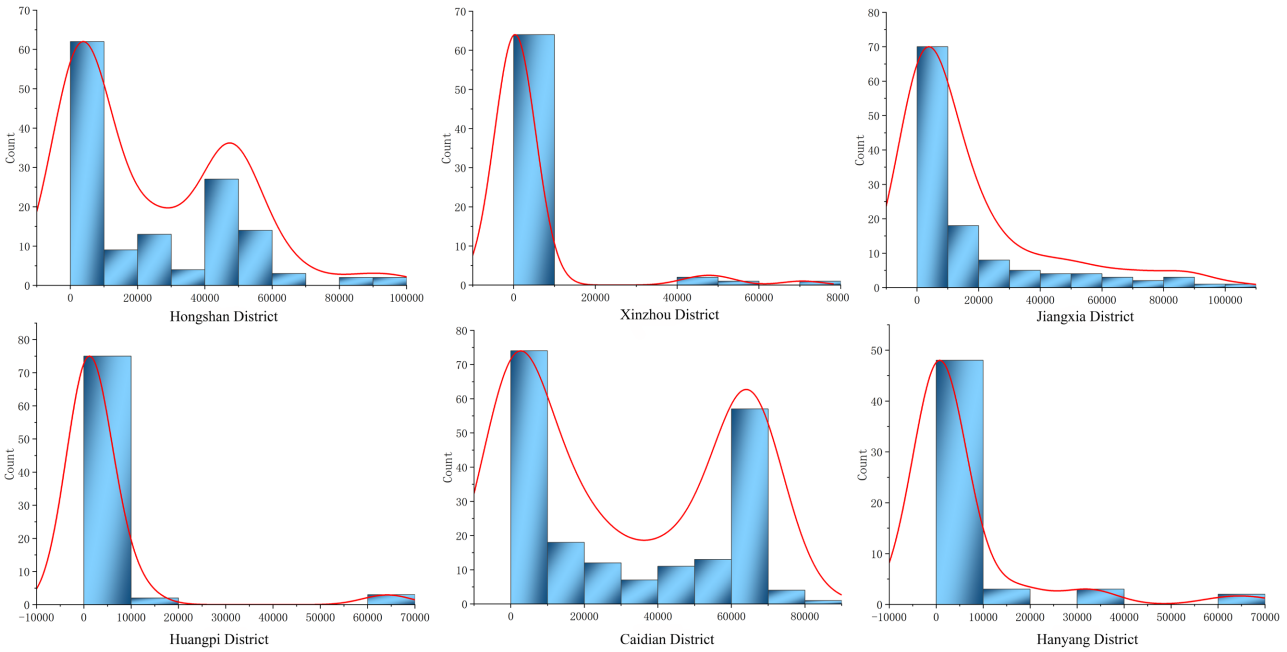

Figure 4. Distribution of accessibility values to public fitness facilities in selected areas of Wuhan. Histograms were created by Origin 2024.

the darker the color and higher the accessibility value, making it easier for nearby community residents to access the services; the further away from the fitness facilities, the lighter the color and lower the accessibility value. This indicates that residents living near public fitness facilities can better enjoy their services, while those living farther away have relatively more difficulty participating in public fitness activities. The geographical location of public fitness facilities largely determines their accessibility level. Considering the differences in accessibility of public fitness facilities in Wuhan City by mode of travel, the study found that whether by walking (threshold 1000 meters), cycling (threshold 3000 meters), or driving

(threshold 6000 meters), the differences in accessibility of public fitness facilities are not significant, meaning the accessibility of public fitness facilities is largely not affected by the mode of travel. The reason is although higher-level modes of travel can allow residents to reach more distant public fitness facilities, higher travel costs and greater spatial distances reduce residents' willingness to reach these facilities (Xie, 2023). The offsetting effects of two factors reach a balanced state, showing no significant differences in the accessibility of public fitness facilities across different modes of travel.

There are significant differences in the accessibility of public fitness facilities among different jurisdictions in Wuhan City. Looking at the distribution of accessibility values across different jurisdictions, the frequency distribution of accessibility values in Xinzhou District, Huangpi District, and Hanyang District all show a unimodal structure, resembling a "cliff" distribution. This stage is the initial stage of development for community accessibility to public fitness facilities, characterized by the majority of communities having low accessibility values, making it difficult for residents to enjoy public fitness facility services. Jurisdictions at this stage need to focus on planning and constructing public fitness facilities to meet residents' fitness needs. The frequency distribution of accessibility values in Caidian District resembles a smile curve, showing a "T-shaped" distribution. This stage is the process stage of development for community accessibility to public fitness facilities, characterized by the largest proportion of communities with either low or high accessibility values, many communities with very low accessibility to public fitness facilities, while also having quite a few communities with higher accessibility, showing a clear bipolar structure with a serious mismatch between supply and demand and poor structural stability. Jurisdictions at this stage should prioritize planning and constructing public fitness facilities for communities with low accessibility, balancing development and equity. The frequency distribution of accessibility values in Jiangxia District decreases stepwise (**Figure 4**), showing a "pyramid" distribution. This stage is also a process stage of development for community accessibility to public fitness facilities, characterized by a decreasing number of communities with higher accessibility values, meaning the number of communities decreases stepwise with the increase in accessibility to public fitness facilities, indicating a basic match between supply and demand and a relatively reasonable supply structure. Jurisdictions at this stage should focus on expanding the proportion of communities with medium accessibility levels to ensure the fitness rights and interests of the majority of residents. The frequency distribution of accessibility values in Hongshan District shows a bimodal structure, resembling a "soil" distribution. This stage is still a process stage of development for community accessibility to public fitness facilities, characterized by the largest proportion of communities with low and medium accessibility values, many communities with medium to low accessibility to public fitness facilities, and a relatively stable supply and demand structure. Jurisdictions at this stage should continue to expand the proportion of communities with medium accessi-

bility levels to ensure that the benefits of public fitness facility construction are more equitably enjoyed by all residents.

7. Equity Analysis of Public Fitness Facilities

Through synthesizing existing research findings (Su, 2023) and data analysis, this study adopts four indicators (floor area ratio, green space ratio, household density, and unit housing price) from the dimensions of residential environment and income level to represent socioeconomic status, and employs the Geodetector method to investigate influencing factors and interaction effects on the accessibility of public fitness facilities. The results show that the floor area ratio, number of households, and housing prices have certain correlations with the accessibility of public fitness facilities. Specifically, the higher the housing price, the easier it is for community residents to access public fitness facilities. The larger the floor area ratio and the more the number of households in a community, the harder it is for residents to access public fitness facilities. That is, the better the socio-economic conditions of the residents, the easier it is to access public fitness facilities, and the worse the economic conditions, the harder it is for residents to reach public fitness facilities.

7.1. Factor Detection Results

The detection results show that the community floor area ratio, number of households, and average community housing price passed the 1% level of significance test (**Table 1**). This indicates that the aforementioned three factors have an impact on the accessibility of public fitness facilities. In the factor detection results, the q value indicates the explanatory power of the factor on the dependent variable, and the impact of the three factors on the accessibility of public fitness facilities from largest to smallest is: average community housing price > number of households in the community > community floor area ratio. This indicates that compared to the number of households and the floor area ratio in the community, the average community housing price has a higher correlation with the accessibility of public fitness facilities. Specifically, the higher the average housing price in a community, the easier it is for residents to access public fitness facility services. It can be seen that higher-income social groups have easier access to public fitness facility services, while low-income groups have difficulty accessing these services. The reasons can be summarized as follows: Firstly, the distribution of public fitness facilities is mostly concentrated near urban centers, while low-income groups often live on the outskirts of the city, making the spatial distance to public fitness facilities too great, resulting in low-income groups having difficulty accessing these facilities. Secondly, the communities where low-income groups live usually have a high floor area ratio and a relatively high population density, resulting in a lack of per capita public fitness facilities and overly crowded public fitness venues, thereby reducing the willingness of low-income groups to access and participate in public fitness activities.

Table 1. Summary of factor detection results.

	Floor area ratio	Greening rate	Number of households
Greening rate	Nonlinear Enhancement	-	-
Number of households	Nonlinear Enhancement	Nonlinear Enhancement	-
House price	Nonlinear Enhancement	Nonlinear Enhancement	Dual-Factor Enhancement

7.2. Interaction Detection Results

The detection results show that the interaction of any two factors enhances the effect on the dependent variable (Table 2), indicating that the explanatory power of any two factors on the accessibility of public fitness facilities is significantly increased after interaction, significantly greater than the explanatory power of two factors independently on the accessibility of public fitness facilities. This indicates that the interaction of factors exacerbates the inequality of different income groups enjoying public fitness facility services. Specifically, communities with both high housing prices and good greenery have better accessibility to public fitness facilities than communities with only one of these factors. Therefore, residents of communities with both factors have much greater opportunities to enjoy public fitness services compared to low-income groups, thereby exacerbating the inequality of public fitness facility services after factor superposition. It is worth noting that the interaction result of community floor area ratio with any factor is nonlinearly enhanced. This indicates that low-income populations living in communities with a high floor area ratio are more likely to be affected by the inequality of accessibility to public fitness facilities. Therefore, in planning for public fitness facilities, special attention should be paid to communities with a high floor area ratio, increasing the efforts to build or expand public fitness facilities to mitigate the spatial distribution inequality of public fitness facilities.

Table 2. Summary of interaction detection results.

	Floor area ratio	Greening rate	Number of households	House price
q statistic	0.022207	0.006824	0.070403	0.089934
P value	0.002028	0.310907	0.000000	0.000000

8. Conclusions and Recommendations

8.1. Research Conclusions

Firstly, from the perspective of accessibility to public fitness facilities, the spatial differentiation pattern of accessibility to public fitness facilities in Wuhan is significant, with differences existing between central urban areas and peripheral urban areas, as well as among different jurisdictions. The study found that the accessibility of public fitness facilities in central areas of Wuhan City is significantly better than in peripheral areas. This indicates that compared to residents in the peripheral areas of Wuhan City, residents in the central areas have easier access to public fitness facilities. Moreover, changing modes of transportation does not

effectively mitigate this accessibility disparity due to spatial attenuation and travel costs. The spatial layout of public fitness facilities is a key factor affecting their accessibility. For communities near public fitness facilities, accessibility is generally higher than for those far from them. This suggests that residents living near public fitness facilities can better enjoy their services, whereas it is relatively difficult for residents living far from such facilities to participate in public fitness activities. The geographical location of public fitness facilities largely determines their level of accessibility. Thus, spatial location is a key factor affecting the accessibility of public fitness facilities, and more rational planning and construction is an effective means to reduce accessibility differences between different areas. For different jurisdictions, there are significant differences in the accessibility of public fitness facilities. If all jurisdictions indiscriminately apply the same development strategy, it could lead to structural distortions where resource idleness coexists with resource shortages (He & Zhang, 2018). Therefore, classifying different jurisdictions into different development stages based on the level of accessibility to public fitness facilities and proposing targeted planning suggestions for each development stage are important measures to improve the distribution structure of public fitness facilities. It is also an effective means to rationally allocate resources and ensure every public fitness facility is fully utilized.

Secondly, from the perspective of equity of public fitness facilities, there exists a certain degree of inequality in the layout of public fitness facilities in Wuhan, leading to spatial deprivation for groups with lower socio-economic status. The study found that factors affecting the accessibility of public fitness facilities in Wuhan City include community floor area ratio, number of households, and average community housing price. Specifically, the higher the community housing price, the smaller the floor area ratio, and the fewer the number of households, the better the accessibility of public fitness facilities in that community, making it easier for residents to access public fitness facilities. In other words, residents with better socio-economic conditions have easier access to public fitness facilities, while low-income groups experience spatial deprivation in enjoying public fitness facilities (Townsend, 2009), unable to enjoy the same level of public services as middle and high-income groups. To reduce this inequality, it is crucial to focus on groups in a socio-economically disadvantaged position, prioritizing the planning and construction of public fitness facilities in communities where these groups live to ensure their right to fitness and make health and harmony a distinctive backdrop of the city. Therefore, using the number of poverty indicators in communities as a criterion for prioritizing the construction of public fitness facilities and building an indicator system to judge the construction priority of public fitness facilities based on socio-economic factors is a powerful means to ensure the fairness of planning and construction of public fitness facilities. Focusing on the living environment of low-income groups and actively constructing public fitness facilities is an important measure to enhance the equity of the layout of public fitness facilities. It is also a powerful means to build an equitable and accessible public fitness

service system and an important practice to ensure that vulnerable groups have equal fitness rights.

8.2. Research Recommendations

By utilizing data analysis at the jurisdictional level, the spatial distribution of public fitness facility accessibility can be precisely identified. Based on the structural characteristics at different development stages, targeted planning recommendations can be proposed to optimize the layout of public fitness facilities. Specifically, this study classifies the development process of public fitness facility accessibility in Wuhan into five stages. The first stage is the "Cliff" stage, characterized by low accessibility levels in most communities. The recommended planning strategy at this stage is to prioritize the development of communities with an extreme shortage of public fitness facilities, addressing the urgent fitness needs of residents in these areas. The second stage is the "I-shaped" stage. Following the first stage, new or renovated fitness facilities have been introduced into communities with the most severe shortages, significantly improving accessibility in some areas. However, a large number of communities still have low accessibility levels. Thus, this stage is characterized by a mix of communities—some with high accessibility and many with low accessibility. The recommended strategy at this stage is to systematically construct public fitness facilities in accordance with the degree of deficiency in each community, ensuring a hierarchical approach to meeting residents' fitness needs. The third stage is the "Pyramid" stage. As a result of previous development efforts, the overall planning and distribution of public fitness facilities become increasingly rational. Communities that were among the first to complete facility planning and construction are gradually surpassed by newly developed communities in terms of accessibility. Consequently, this stage is characterized by a stepwise reduction in the number of communities as accessibility improves. The recommended strategy at this stage is to continue constructing or upgrading fitness facilities in low-accessibility communities to further expand the proportion of communities with moderate accessibility levels. The fourth stage is the "Earth" stage. With the development achieved in the third stage, the number of communities with moderate accessibility has significantly increased. Therefore, this stage is characterized by a large number of communities with either moderate or low levels of fitness facility accessibility. The recommended strategy at this stage is to persist in constructing or upgrading fitness facilities in low-accessibility communities, continually expanding the proportion of moderately accessible communities. The goal is to establish a stable "olive-shaped" structure, where the majority of communities maintain a moderate level of accessibility to public fitness facilities. The five stages of public fitness facility accessibility development are interconnected and progressive. Adapting to these developmental patterns and implementing different strategies at different stages is essential for ensuring a rational layout of public fitness facilities. This approach not only facilitates gradual progression from one stage to the next but also ultimately contributes to build-

ing an equitable and accessible public fitness service system.

By analyzing the spatial distribution of public fitness facility accessibility values, the development stage of a jurisdiction can be identified, allowing for the formulation of an appropriate overall development strategy for public fitness facilities in the area. Further analysis of the socioeconomic conditions of different communities within the jurisdiction enables the assessment of facility shortages in each community, establishing a prioritized sequence for facility construction. Specifically, a comprehensive and precise collection of statistical data on all communities within the jurisdiction should be conducted. Using geographic detectors, key variables affecting the accessibility of public fitness facilities—such as community floor area ratio, average housing prices, and the number of residential households—can be identified as evaluation indicators. Special attention should be given to indicators reflecting poverty, such as high floor area ratios, large numbers of households, and low housing prices. The priority level for public fitness facility construction should be determined based on the number of poverty-indicating variables in a given community—the greater the number of such indicators, the higher the construction priority for that community. Facilities should then be constructed sequentially from the highest to the lowest priority. For communities at the same priority level, population density should be calculated based on community population data and land area. The demand for public fitness facilities should then be assessed based on population density, with higher-density communities indicating greater demand. This demand assessment should establish a secondary level of priority for facility planning and construction, ensuring a stepwise approach to new or renovated public fitness facilities that proactively address the fitness needs of low-income groups. Reducing inequalities in public fitness facility services caused by socio-economic disparities, while steadily enhancing accessibility on the basis of increasing fairness, is a crucial means of addressing shortages and uneven distribution of fitness facility supply. This strategy serves as an effective measure for mitigating urban spatial deprivation and promoting the equalization of public rights. Moreover, it represents an essential practice in ensuring that the benefits of modernization are shared by all members of society.

Availability of Data and Materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Conflicts of Interest

The authors declare that they have no competing interests

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