

Article

A Community-Oriented Accessibility Index of Public Health Service Facilities: A Case Study of Wuchang District, Wuhan, China

Hong Xu ^{1,2,*}, Jin Zhao ¹ and Xincan Yu ¹

¹ School of Urban Construction, Wuhan University of Science and Technology, Wuhan 430065, China; zhaojin@wust.edu.cn (J.Z.); yuxincan@wust.edu.cn (X.Y.)

² Hubei Provincial Engineering Research Center of Urban Regeneration, Wuhan University of Science and Technology, Wuhan 430065, China

* Correspondence: xuhong@wust.edu.cn

Abstract: Public health service facilities are the fundamental component of urban medical and health services, and they are critical for realizing urban residents' enjoyment of equitable and convenient medical services in sustainable smart cities. Spatial accessibility is an important indicator for evaluating the rationality of the layout of medical facilities from the perspective of sustainability. This study introduces a community-oriented accessibility (CA) index of public health service facilities, which considers a weighted average time model and the 15 min living circle standard for constraint, and even the service capacity of medical facilities. This study uses the proposed index to investigate the spatial accessibility of public health service facilities in the study area of Wuchang, Wuhan, China. Compared with the E2SFCA model, the proposed CA model joins the construction concept of an urban living circle, which is consistent with the domestic urban construction goals. The main findings include the following: (1) The community-oriented accessibility index of public health service facilities in the study area showed a gradual decline in the middle to sides under the walking mode and a high index in the north and low index in the south under the vehicle travel mode. (2) The calculated CA accessibility results are quite different between the walking and vehicular modes, and they are mainly affected by the allocation of the number of facilities and the distribution of the population. (3) Compared to the previous method, the calculated CA index results are more reflective of the actual situation and could be useful in guiding the spatial layout of the facilities more finely. This research explores the sustainable utilization of land resources in the planning of medical facilities and promotes the healthy and sustainable development of cities. In future studies, the population's actual traffic conditions, weather, and holidays will be considered to further research on the accessibility of different groups and the specific impact of these factors on accessibility so as to promote people-friendly accessibility for sustainable smart cities.

Keywords: public health services; community-oriented accessibility index; spatial accessibility



Citation: Xu, H.; Zhao, J.; Yu, X. A Community-Oriented Accessibility Index of Public Health Service Facilities: A Case Study of Wuchang District, Wuhan, China. *Sustainability* **2023**, *15*, 10870. <https://doi.org/10.3390/su151410870>

Academic Editor: Stanislav Shmelev

Received: 10 June 2023

Revised: 8 July 2023

Accepted: 8 July 2023

Published: 11 July 2023



Copyright: © 2023 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (<https://creativecommons.org/licenses/by/4.0/>).

1. Introduction

All public health facilities should be environmentally sustainable in cities, which is one of the critical urban sustainability performances, especially for sustainable smart cities [1]. Medical and health service facilities play an important role in guaranteeing the life and health safety of residents and assume important responsibilities in public service facilities [2]. Since the outbreak of the COVID-19 pandemic in 2020, researchers all over the world have begun to pay renewed attention to the system and layout of medical facilities. The public health service facilities, as the carrier of the primary medical and health service system, are the first protection to control diseases, while providing comprehensive primary health services for community residents in ordinary times. In 2016, the "Tutorial for Outline of the Healthy China 2030 Plan" issued by the state mentioned that basic medical and

health resources should be reasonably distributed according to the residential population and service radius, and a 15 min basic medical and health service circle should be basically formed by 2030 [3]. Therefore, it is crucial for the healthy development of cities and the quality of people's lives to ensure that residents can reach the nearest medical service point within 15 min by reasonably allocating community medical and health service facilities in cities [4], especially for the era of urban sustainability. At present, urban construction agencies pay more and more attention to the quality of people's living environment and pay attention to healthy development. However, when facing major public health emergencies, many cities revealed problems of uneven distribution of medical facilities and unreasonable distribution of grades.

The problems generated by the space planning of medical facilities in urban areas and the existing theoretical gaps have motivated the development of medical facility planning studies in recent years in Wuhan and other cities. A recent study combined text sentiment analysis techniques with geographic information system technology and used a coordination degree model to evaluate the dynamic demand for medical facilities in Wuhan based on social media data and medical facility data [5]. The Kernel Density Two-Step Floating Catchment Area (KD2SFCA) and shortest distance methods were used to calculate the accessibility of designated COVID-19 Fangcang hospitals and fever clinics in the Wuhan Metropolitan Development Zone [6]. These works proposed methods of evaluating instruments for the government and urban planners that aim at the planning of the urban distribution of medical facilities.

Furthermore, in May 2022, Wuhan issued the Wuhan Regional Health Plan (2021–2025), which aims to optimize the allocation of medical and health resources, expand the capacity of medical resources, promote a balanced distribution of medical resources in the city, and improve the efficiency of medical and health resource utilization. It is worth noting that this study fits well with the goals of this plan. Among them, the plan proposes the construction standards of public health service centers and public health service stations. For example, one public health service center or station is set up on each street. A neighborhood with a permanent population of more than 100,000 people may set up one additional public health service center or public health service station. It thus becomes necessary to suggest a methodology that allows guiding decision-makers on what is the best strategy to lay out the public health facilities in cities. Therefore, this study aims to provide a basis and suggestions for Wuhan City to optimize the allocation of urban medical facilities.

This paper serves this purpose by developing and applying the community-oriented accessibility (CA) index focused on the balanced layout of public health facilities. This model has the community as the research unit. This research contributes to the field of spatial planning as it suggests the rational spatial layout of public health facilities, which would fill the supply and demand gap and would meet the requirements of the residents, to promote healthy and sustainable development of cities. The research collected study data through various open data platforms such as the official website of the government, Amap, and the National Geographic Information Platform. This research focuses on the discussion and innovation of methods, and the methods adopted only focus on the factors of quantity allocation, space layout, and service level of service facilities.

This article consists of six sections. Section 1 presents an introduction to the issue of distribution of urban medical resources, and the development needs of medical service facilities in Wuhan, China. Section 2 provides an overview of the research on spatial accessibility evaluation and medical service facility planning. Section 3 presents the research methodology. Section 4 presents the research materials. Section 5 describes the result and discusses the issue, while Section 6 defines the conclusion, including recommendations for future studies.

2. Literature Review

2.1. Planning for Public Health Service Facilities

Many research works focused on medical and health facilities have gradually moved from spatial equality to social equality. For example, more attention was paid to the fairness and equality of different social groups in the allocation of facilities. Van, D. et al. [7] used self-rated health to evaluate the health situation in different countries in 2004 and found that health inequalities were different in each country, but beneficial for high-income people. Ehara, A. [8] proposed the relationship between the number of medical facilities and the urban population. The high correlations between population and emergency medical facilities were demonstrated through statistics on the number of medical facilities, the number of physicians, and the urban population. Hyun, P. et al. [9] investigated demographic and spatial changes in Korea since 2000. The spatial correlations between population and medical facilities were investigated from the perspective of the spatial distribution of the elderly and children. It can be seen that the main reference values of medical facility planning are mainly population size and population distribution. The development of transportation also affects medical resource services. For example, Abiiro, G. and Mbera, G. [10] took population distribution, topography, and land use characteristics into account, so as to establish the service coverage of the primary health facility model, which enables residents to reach nearby community health facilities using three modes of travel (walking, cycling, and bus). As a result, context-specific gaps could be identified to inform the design of such reforms. In addition, traffic factors and the service coverage of medical resources can be considered for better design.

At present, the healthcare services framework includes hospital services, public health services, and primary medical services in China. The framework of the public health service system is based on public health service centers and supplemented by public health service stations, medical clinics, and infirmaries. This paper mainly focuses on public health service centers and public health service stations. A public health service center is a general center for prevention, medical treatment, rehabilitation, and health promotion healthcare activities, which are mainly provided to residents in the community with the purpose of hoping that residents can seek medical treatment for their underlying diseases without leaving the community. Public health services are smaller in size and are designed to triage patients with common and minor illnesses [11,12]. There are relatively few studies on the planning of primary medical services facilities in China. This study focuses on public health facility planning by considering population distribution, facility service levels, transportation, etc.

2.2. Spatial Accessibility Evaluation

For the evaluation of medical and health facility services, the more common research methods can be roughly divided into two types: traditional mathematical statistical methods, and evaluation and analysis based on spatial accessibility. Traditional mathematical statistical methods mainly use Lorenz curves and Gini coefficient coefficients to quantitatively evaluate the total amount of medical resources and population [13,14]. Such approaches tend to ignore the relationship between the spatial level of service of medical facilities and users.

Accessibility refers to the quantitative expression of residents' desire and ability to overcome resistance such as distance, travel time, and cost to reach a service facility or activity venue, which is an important criterion for measuring the rationality of the spatial distribution of urban service facilities [15]. It can be a common method to measure whether the resource allocation is reasonable or not and is widely used in the accessibility measurement of various public facilities [16]. In the field of healthcare, accessibility can effectively identify the problems in the resource allocation of healthcare facilities and provide a reference for decision-makers to solve the inequitable spatial distributions of medical and health resources [17].

Previous scholars have also developed different accessibility research methods, mainly including the proportional method [18], the average distance method [19], the opportunity-based cumulative method [20], and the spatial interaction-based method [21]. The average distance method is more intuitive and easier to understand among all accessibility evaluation methods, mainly using time and spatial distance as indicators to measure accessibility [22]; the calculation formula is

$$A_i = \frac{1}{n-1} \sum_{\substack{j=1 \\ j \neq i}}^n (d_{ij}) \quad (1)$$

where A_i is accessibility of settlement; i is the settlement; and d_{ij} is the minimum resistance between data points i and j , which is in terms of distance and time.

In order to consider multiple factors such as the scale of demand points and service capacity of facility points, research scholars modified this formula and proposed the weighted distance method, two-step mobile search method, and gravity model to evaluate accessibility. For example, the two-step floating catchment area analysis method evaluates potential spatial accessibility based on the maximum acceptable distance for an individual while considering the limitation of distance decay [16,23,24]. Hu et al. [25] integrated different travel modes and park attractiveness coefficients into a Gaussian E2SFCA model and used network analysis to compare and analyze 10, 15, and 20 min scenarios to achieve park accessibility. Salvacion [26] studied the measurement of spatial accessibility of healthcare facilities based on distance (i.e., travel time) and area-based metrics (i.e., enhanced two-step floating catchment area analysis or E2SFCA). The gravity model determines the accessibility of a region by summarizing the opportunities available in each region and the difficulty of reaching the region by different modes [27]. Nai et al. [28] analyzed the distribution characteristics and accessibility of hospitals in Wuhan City by using an improved gravity model while considering the population density and the influence of residents on the choice of medical facilities. Song et al. [29] considered the spatial interaction between supply and demand, which added probabilistic rules to obtain the New Gravity P-Median Model, and empirically demonstrated that the model could be applied to solve the problems in terms of facility location and size allocation with high time complexity. In general, there are many factors to be considered in healthcare facility planning, such as travel impedance, different modes of transportation, population size, service ability of facilities, and residents' medical choices. It is necessary to propose a methodology that considers these factors together.

The weighted average distance method further considers multiple impacts such as travel traffic patterns, destination scale, and land use. In this study, factors such as travel impedance, different modes of transportation, population size, service ability of facilities, and residents' medical choices are considered. We improved the weighted average distance method to construct a community-oriented accessibility model based on the community as the research unit. It assesses accessibility to public health facilities at the community level. This research contributes to the field of spatial planning as it suggests the rational spatial layout of public health facilities, which would fill the supply and demand gap and would meet the requirements of the residents.

3. Methodology

For the planning of public health service facilities, it is necessary to consider the influence of community population size, distance priority, scale level, and service ability of facilities [16,30–33]. The weighted average distance method was improved in alignment with these factors. This section addresses the calculation formula and process flow of the community-oriented accessibility (CA) index for introducing the improvement.

3.1. Community-Oriented Accessibility Index

Based on the calculation principle of the weighted average distance method, the formula is improved according to the factors examined by this research. (1) Considering

the distance between population distribution and public health service facilities, this study introduces the weight of facility selection and takes people reaching public health facilities within 15 min travel as the criterion. (2) This paper considers the service ability of different-grade public health facilities. (3) This paper increases the impact factor of the size of the resident population. Therefore, the CA model is proposed to measure the accessibility of public health services in community areas. The better the service ability of the facility, the greater the weight of residents' choice, which will increase the accessibility of the facility. This research model formulas are represented as follows:

$$CA_k = \frac{1}{n} \sum_{i \in S_k} A_i, \quad A_i = \text{average} \left(\sum \frac{t_{ij} W_{ij}}{M_j} \right) \quad (2)$$

$$M_j = \frac{P_j}{\sum_{s \in (t_{ij} \leq 15 \text{ min})} P_{js}} \quad (3)$$

$$W_{ij} = \begin{cases} 1, & (t_{ij} \leq 15 \text{ min}) \\ 0, & (t_{ij} > 15 \text{ min}) \end{cases} \quad (4)$$

where CA_k represents the accessibility index of public health services in the community k . n is the number of all public health services in the community k . t_{ij} represents the travel time in population density fishnet i and public health facility j . M_j represents the service ability of public health facility j ; P_j represents the number of people served by public health facilities j , using different grades of health facility service population standards; P_{js} represents the total number of people served in s area; and S represents the range of 15 min travel from facility j . W_{ij} represents the weight of the choice of facility j by population density fishnet i , which is judged by the coverage of the 15 min living circle area of the population density fishnet i . The weight of facility j covered by the 15 min living circle of i taken is as 1, and that not covered is taken as 0.

For example (Figure 1), the service area of facility A covering 7, 8, 9, and so on is a cell center, so the actual population served by facility A is the sum of the population density of 10 cells. Cell 8 is covered by the A service area and is not covered by the B service extent, so the A facility selection probability of cell 8 is 1, and the B facility selection probability is 0. Then the CA of cell 8 is the ratio of travel time between 8 and A to the service ability of facility A.

3.2. The Calculation Flow of the Proposed Index

The proposed index can be calculated through the following steps:

- i. Collecting data on public health facilities, population density, community, and road network in the study area.
- ii. Generating the spatial map showing the distribution of different communities, public health facilities, and populations in the study area, as well as building a road network database of the study area.
- iii. Creating a population density fishnet for the study area.
- iv. Calculating the service ability of public health facilities of the study area.
- v. Judging the facilities covered by the 15 min living circle of the population fishnet.
- vi. Utilizing the CA model for public health facility accessibility in different communities of the study area.
- vii. Analyzing the results and giving recommendations and conclusions.

From steps i–vii, the methods were drawn and divided into three phases: (a) data processing phase, (b) CA model processing phase, and (c) output results and discussion phase (Figure 2).

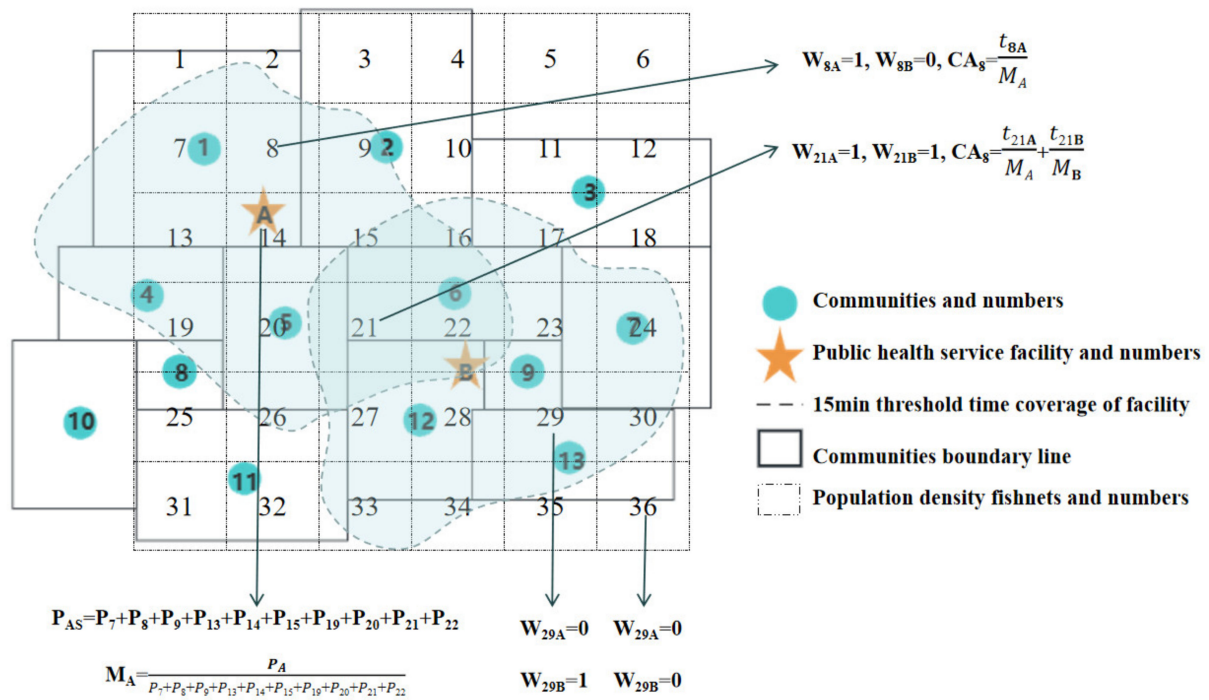


Figure 1. Calculation example of the proposed CA index.

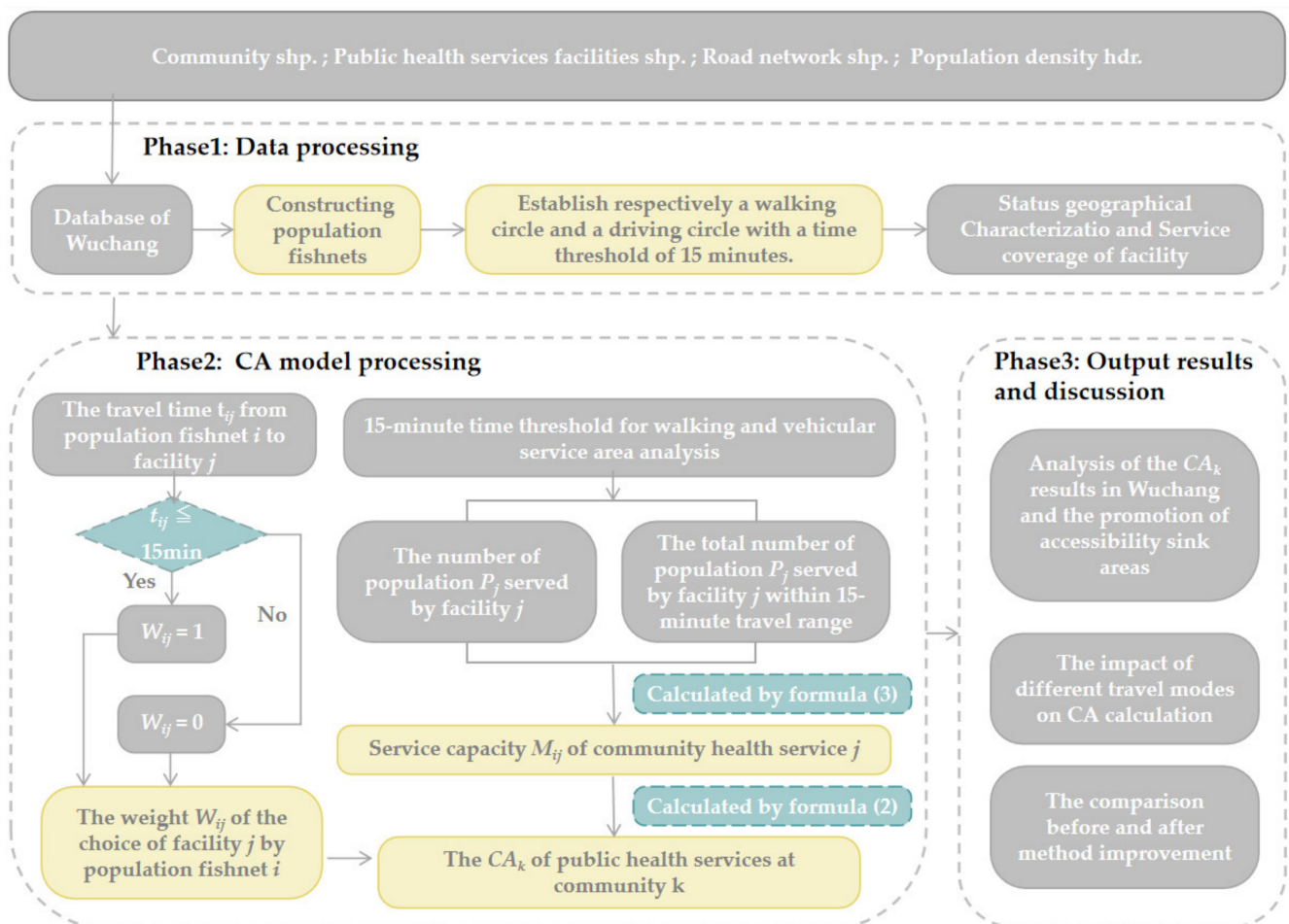


Figure 2. The calculation flow of the proposed CA index.

In the first phase, this study collated all the data to build a basic database for our research. At present, the planning of a network of 15 min urban community living circles suitable for living, working, and traveling is being actively promoted in China [34]. The 15 min living circle refers to the basic service needs of life that can be met within 15 min of walking, including medical services, and the distance of 15 min walking is generally 1–1.5 km. Therefore, this study builds 1000 m $\times$ 1000 m fishnets and then extracts population information from 967 m $\times$ 967 m cell size population density raster to the corresponding fishnet label. This study uses the service area analysis to determine the travel range for the 15 min time threshold to analyze the spatial layout and service coverage of public health facilities.

In the second phase, this study uses the OD cost matrix analysis to calculate the minimum impedance travel time from each population fishnet to all facilities, calculated in minutes, and obtain t_{ij} . Residents often choose the service facility that is the shortest distance from them [35]. This study takes the 15 min living circle as the judgment standard, and according to the t_{ij} calculated in the previous step. Here, ≤ 15 min means that the facility j far from the fishnet i is within the 15 min travel time by walking or driving. When the possibility of the population fishnet i choosing this facility j is relatively large, the selection weight value is 1. In the opposite case, the selection weight value is 0. The weight values determined in this study are only used to distinguish the selectivity of facilities inside and outside the 15 min living circle of the settlement, assuming 1 and 0.

Different population sizes of residential areas within the region have different demands for service facilities [36]. When the service demand increases and the population that the facility can serve is limited, the service capacity of the facility will be affected, which may increase the cost of medical treatment time for residents [37]. Therefore, we use the ratio of the service population to the resident population to represent the service ability of a public health facility. This study calculates the 15 min time threshold for walking and vehicular service area by network analysis and counts the total population of fishnets within a 15 min time threshold travel range of facility j . Different grades of public health service facilities serve different populations [2]. According to the Wuhan Regional Health Plan (2021–2025) [38], the population served by public health service centers is determined to be 30,000, and the population served by public health service stations is determined to be 15,000. These two values were used in this research as the number of people served by facility j .

Finally, according to the CA model calculation Formula (2), the CA_{ij} of the public health service facility accessibility of the fishnets is calculated. Inverse distance weighting (IDW) interpolation is used here based on the assumption that things that are closer to each other are more similar than things that are farther away from each other, assigning more weight to the point closest to the predicted location, while the weight decreases as a function of distance [39,40]. The assumption of the IDW method is similar to the spatial distribution characteristics of medical and health facilities. Therefore, we use the inverse distance weighting method to perform interpolation analysis and generate an accessibility analysis map of public health service facilities in the study area.

In the third phase, this study summarizes the existing problems of public health facility configuration in the study area based on the results of CA analysis. This study discusses the difference in accessibility calculation results under two different modes of transportation, namely walking and driving; compares the differences in model calculation before and after improvement; and presents the advantages of this proposed model.

4. Material

4.1. Study Area

This study considered a city located in the state of Wuhan, China, which is an old-town city and is located in the eastern part of Wuhan. Wuchang is a municipal district of Wuhan City, Hubei Province, and this study covers the entire district of Wuchang District, with a total area of 82.4 square kilometers, including 13 communities (Figure 3). There is a large

population of residents. With the growing population, aging facilities, and an insufficient number of facilities, the allocation of medical services in the old city is relatively inadequate compared to the new town. In this context, this research used Wuchang District as our research area. Wuchang is located in the central urban area of Wuhan, in which a large number of residential areas are concentrated, and considering the availability of data, this study takes communities in Wuchang as the study area.

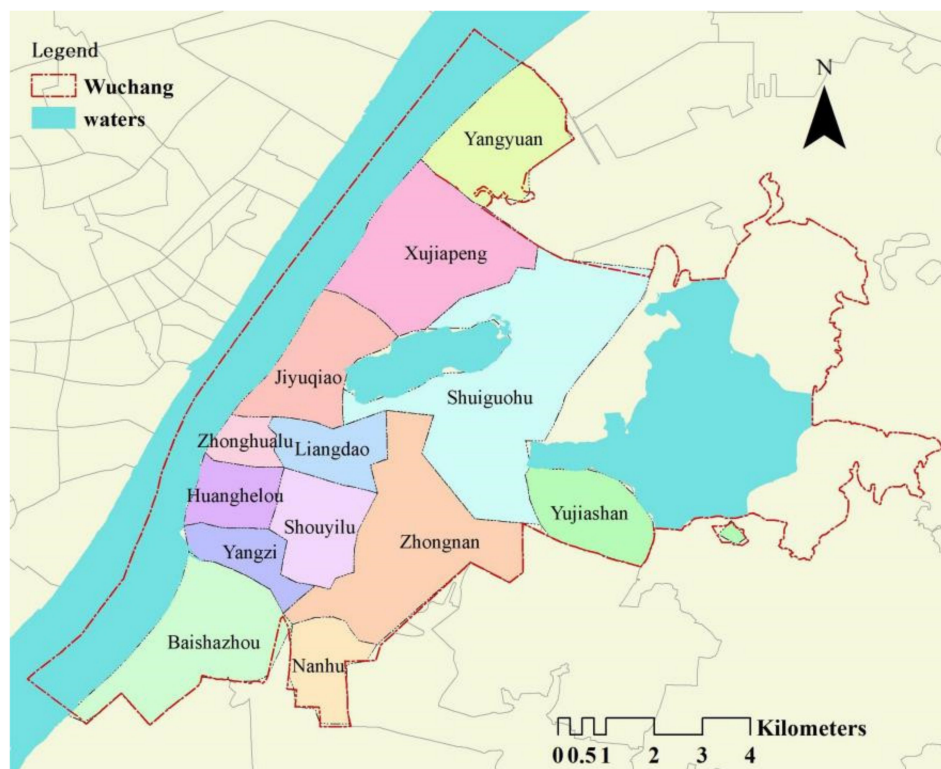


Figure 3. Wuchang District and communities.

4.2. Data Source

For this study, geographical maps of Wuchang, basic geographical data on road networks, data on public health facilities, and population density in different communities of Wuchang were mainly collected to construct the research database. The statistics of the source of the research data are shown in the table (Table 1); we uniformly adopted Xian 1980 3 Degree GK CM 102E as the projected coordinate system.

Table 1. Research data source statistics.

Data Name	Data Source	Data Date	Data Format
Community division map	Guihuayun sharing platform, the website: http://www.guihuayun.com/maps/region_amap.php (accessed on 10 May 2023)	29 May 2022	Vector
Road network	Open Street Map open-source map download platform, the website: www.openstreetmap.org (accessed on 10 May 2023)	30 May 2022	Vector
Public health service facility POI	Guihuayun sharing platform, the website: http://guihuayun.com/poi/ (accessed on 10 May 2023)	31 May 2022	Excel
Population density	https://www.swguancha.com/ (accessed on 10 May 2023)	30 May 2022	Vector

For this study, the data on the main road network in Wuhan were obtained from the OpenStreetMap platform. According to the different levels of roads for stratification and setting attributes such as traffic speed and walking speed, the study area only involved provincial roads, county roads, and urban roads. Therefore, provincial roads were determined to be 40 km/h, county roads were determined to be 30 km/h, and urban roads were determined to be 20 km/h. The one-minute walking distance of people is about 60–100 m, and in this study, the walking distance per minute was assumed to be 80 m. In this study, we constructed a road network model in Wuchang District regardless of the traffic direction as the basic model for network analysis (Figure 4).

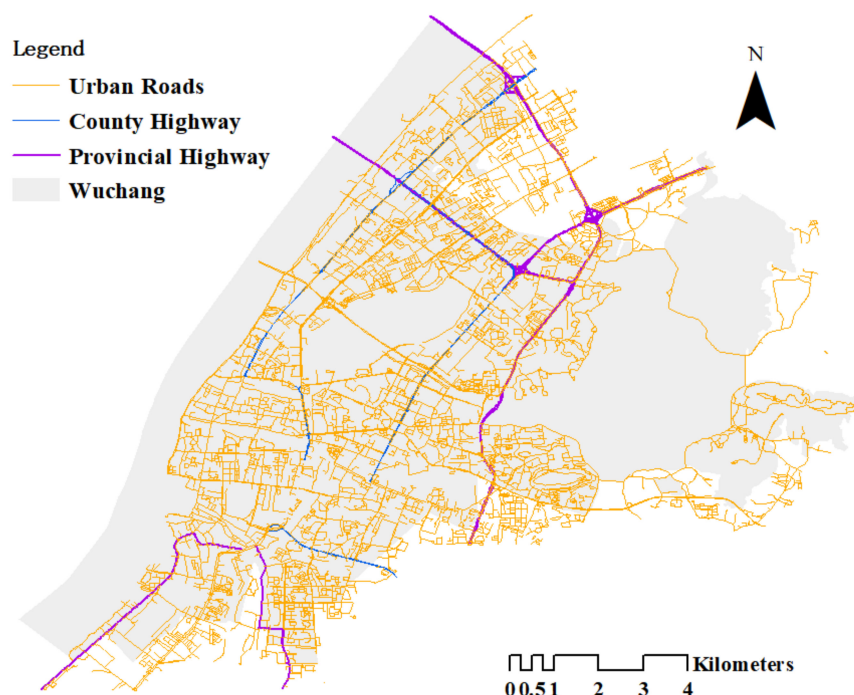


Figure 4. Wuchang District urban road network.

Based on the medical care service category in the POI classification of AutoNavi Map, we crawled a total of 2018 POI data of medical facilities in Wuchang District, Wuhan; excluded duplicated data and non-Wuchang districts such as Qingshan District and Hongshan District; and screened the data to finally collect 20 public health service centers and 19 public health service stations (Figure 5). It can be intuitively seen that there are medical and health service facilities in 13 communities, but the number is unevenly distributed, and the distribution is relatively dense in the western and southern communities of Wuchang District. By counting the number of public health service facilities (Figure 6), it can be seen that there are large differences in the number of streets.

In this study, the population density distribution data raster in Wuchang, Wuhan City, was obtained from the Digital Observation website, and each raster cell size is 967×967 m. It can be seen from the population density distribution map of Wuchang (Figure 7) that the population is mainly concentrated in Zhonghua Road, Yangzi, Huanghelou, Xujiapeng, and Zhongnan communities and the southeastern population is less distributed. A total of 78 grids were created for fishnets. After extraction analysis, we obtained the population data corresponding to the center point of the grid to obtain a population fishnet map (Figure 8). We studied the community by dividing it into cells based on the standard of 15 min walk living circle. The population distribution of Wuchang District varies greatly in space; it is concentrated in the central part and gradually decreases to the north and south. We built a $1000 \text{ m} \times 1000 \text{ m}$ cell grid. There is a large area of water in Wuchang District, namely East Lake and Shahu Lake. Therefore, after removing the cell grid with

a population of 0, a cell grid containing the population number was formed. We turned the cell grid into point data, 78 points in total, and used spatial connection to add the population density data of Wuchang with population to the point, continuing to study OD costing at a later phase.

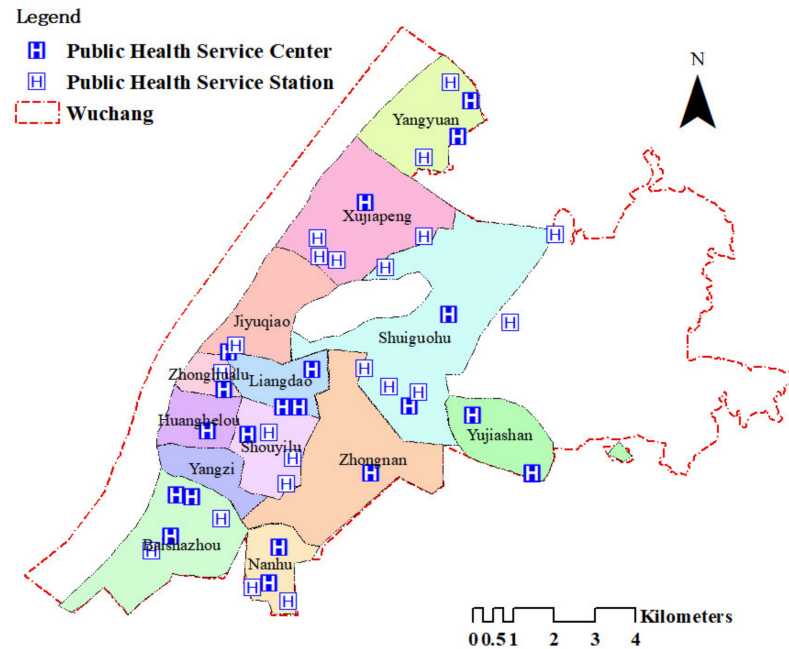


Figure 5. Spatial distribution of public health service facilities in Wuchang.

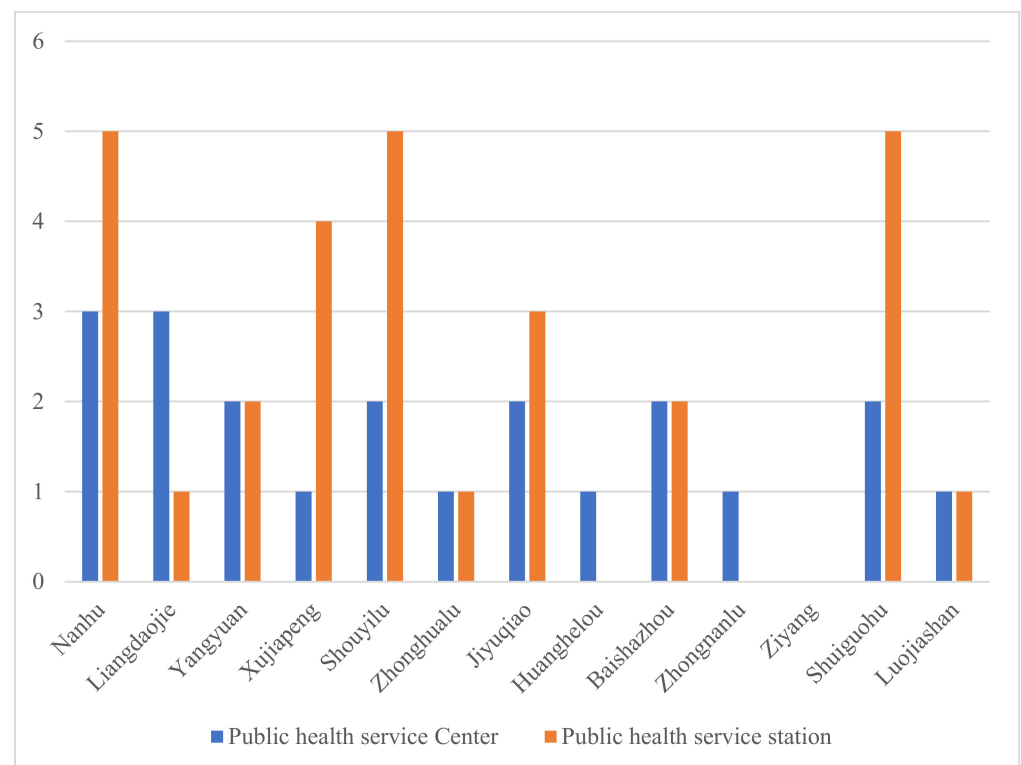


Figure 6. Spatial distribution of public health service facilities in Wuchang.

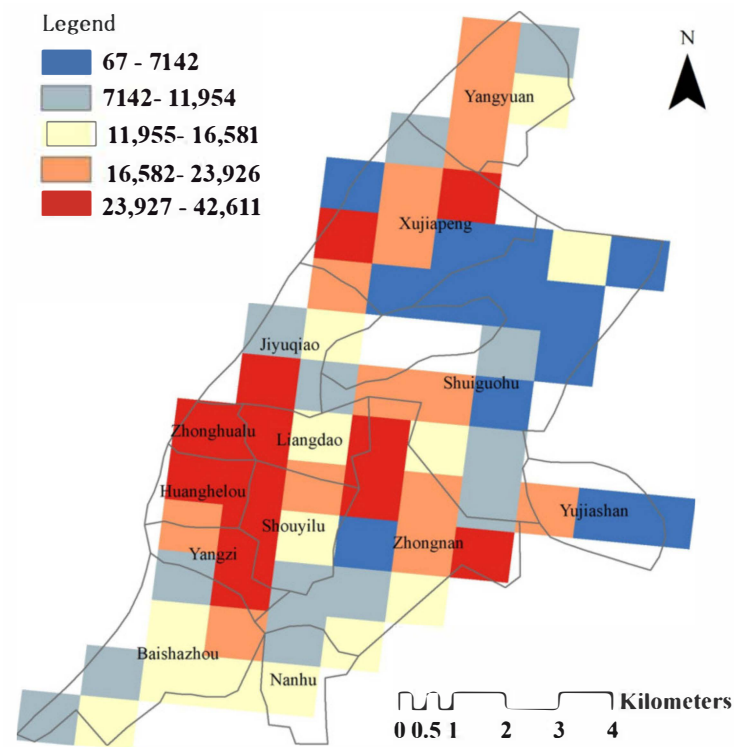


Figure 7. Population density distribution in Wuchang.

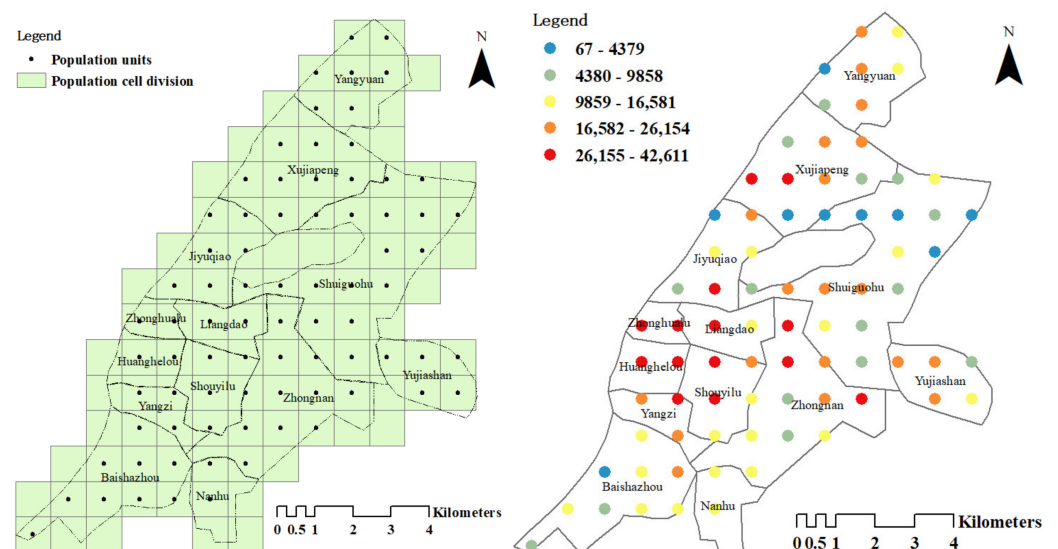


Figure 8. Population fishnet of Wuchang.

5. Results and Discussion

The evaluation results were obtained through model calculation. The existing problems in Wuchang District are analyzed and summarized, and the optimization strategy is proposed. This article also discusses the results of walking and driving and compares the differences in the analysis results before and after the improvement of the calculation model.

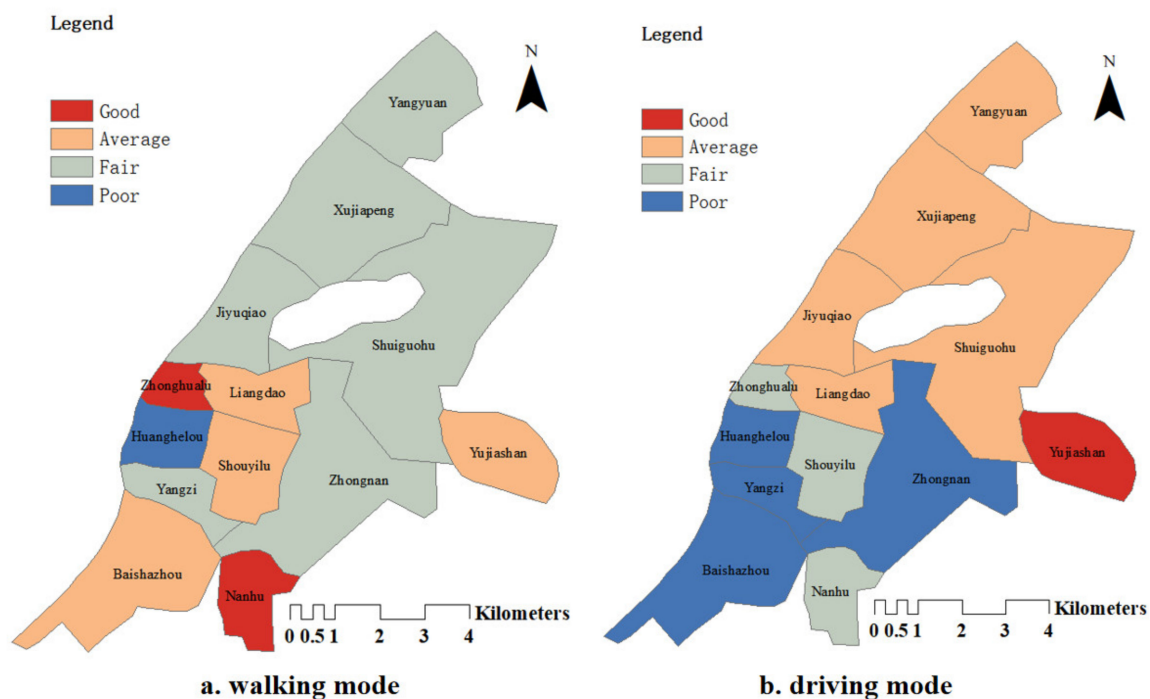
5.1. The CA Results

We calculated facility accessibility for both walking and driving modes according to the CA model (Figure 9). The result is divided into four levels, namely good, average, fair, and poor, by the natural break (Jenks) method in order to facilitate map reading (Table 2).

Table 2. Reclassification of accessibility map.

Class	Values of Walk Model	Values of Walk Model	Descriptor
1	5.02–16.45	65.96	Good
2	16.46–49.38	65.97–116.34	Average
3	49.39–66.64	116.35–151.45	Fair
4	66.65–80.00	151.46–170.57	Poor

In the pedestrian travel mode, the community accessibility in the south is higher than that in the north, with the Zhonghualu community and the Nanhu community having the best accessibility. In the mode of driving travel, the community accessibility in the north is higher than that in the south, and the Yujiashan community at the eastern end has the best accessibility. There are great differences in community accessibility between the two modes of transportation. We analyze the inverse distance weight difference of the accessibility of each fishnet unit to obtain the accessibility index of public facilities in Wuchang overall (Figure 10). In the walking mode, the accessibility single core radiates to the periphery and gradually decreases to the peripheral areas, and the accessibility changes rapidly from the middle to the periphery. The central part has the best medical accessibility, covering the communities of Zhonghualu, Liangdao, Shouyilu, and Yujiashan, as well as the southern part of the Fruithu community. In the vehicle mode, the layout state shows a gradual decrease in accessibility from the north to the south.

**Figure 9.** The community-oriented accessibility index of public health service facilities in Wuchang.

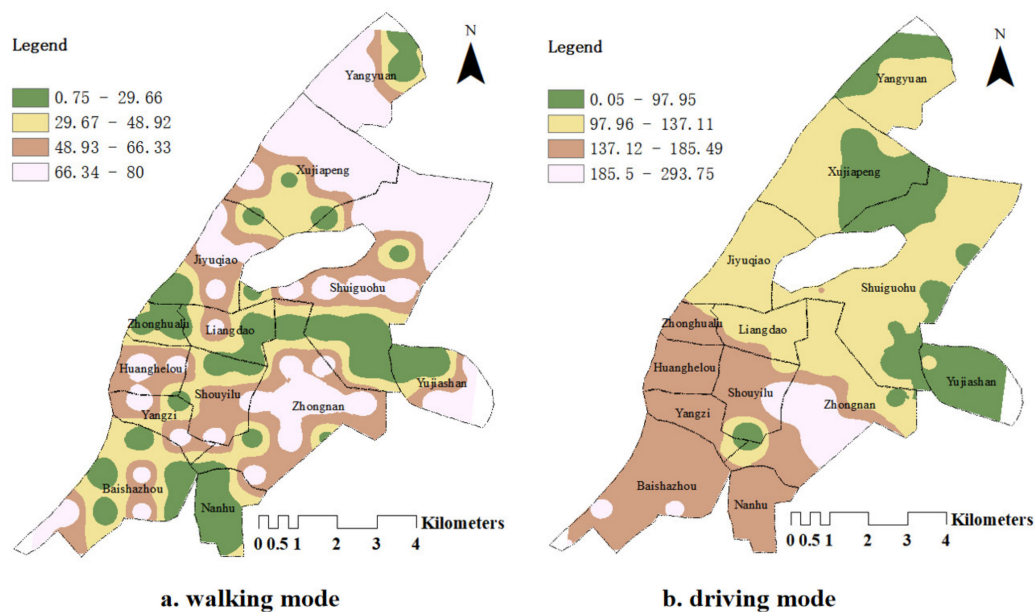


Figure 10. The accessibility of public health service facilities in Wuchang.

5.2. Discussion

5.2.1. The Effect of Transport Model

In the early analysis, we calculated the CA index from the two travel modes of walking and driving, taking 60 m/min for walking and 450 m/min for driving, and the final results are quite different. This study further explores the relationship between the different travel modes and the accessibility of public health services facilities in the community. This study performs a service area analysis to calculate facility coverage in both vehicular and walk modes (Figure 11), using a 15 min time as the time threshold. This study has the following findings: Among the 78 population data points, 39 points can be reached within 15 min in walking mode, serving a total of 677,790 people, accounting for 53.36% of the total population of Wuchang. In the driving mode, almost the entire area of Wuchang can be reached within 15 min. Therefore, according to Equation (3), these demographic data will affect the facility's ability calculation. Each facility has a fixed limit on the number of people served based on the scale and rank. When the actual number of people seeking medical care increases, the demand for medical services will increase. However, the supply of facilities remains unchanged, and demand will outstrip supply. This may lead to greater pressure on some community health service facilities, causing traffic congestion in the surrounding areas and resulting in difficulties for community residents seeking medical treatment, long waiting times, etc. When community health service facilities with fewer services cannot reach enough markets, it could lead to stagnation of development and waste resources of primary medical and health facilities [41]. Therefore, the actual time it takes for residents to receive medical services will increase, resulting in a decrease in the M_{ij} calculation indicator of service ability (Figure 12).

From the M_{ij} calculation value, with 1 as the demarcation, >1 means that the service capability is good, and ≤ 1 means a weak service ability. In the pedestrian mode, the facilities with better service ability are mainly concentrated in the Baishazhou community, Yangyuan community, and Nanhu community. In the vehicle mode, the facilities with better service ability are mainly distributed in Yangyuan community, Zhongnan community, and Yujiashan community. The walking distance is more limited, and residents mostly choose nearby facilities, so the M_{ij} is more affected by the population distribution. The range of travel by car is large; the number of facilities that residents can choose from increases accordingly, and the M_{ij} of each facility is less than 1. In general, facilities with better service capacity in Wuchang are concentrated in areas with lower population density. Therefore,

when planning the layout, reasonable allocation of facilities of different levels should match the spatial distribution of the population.

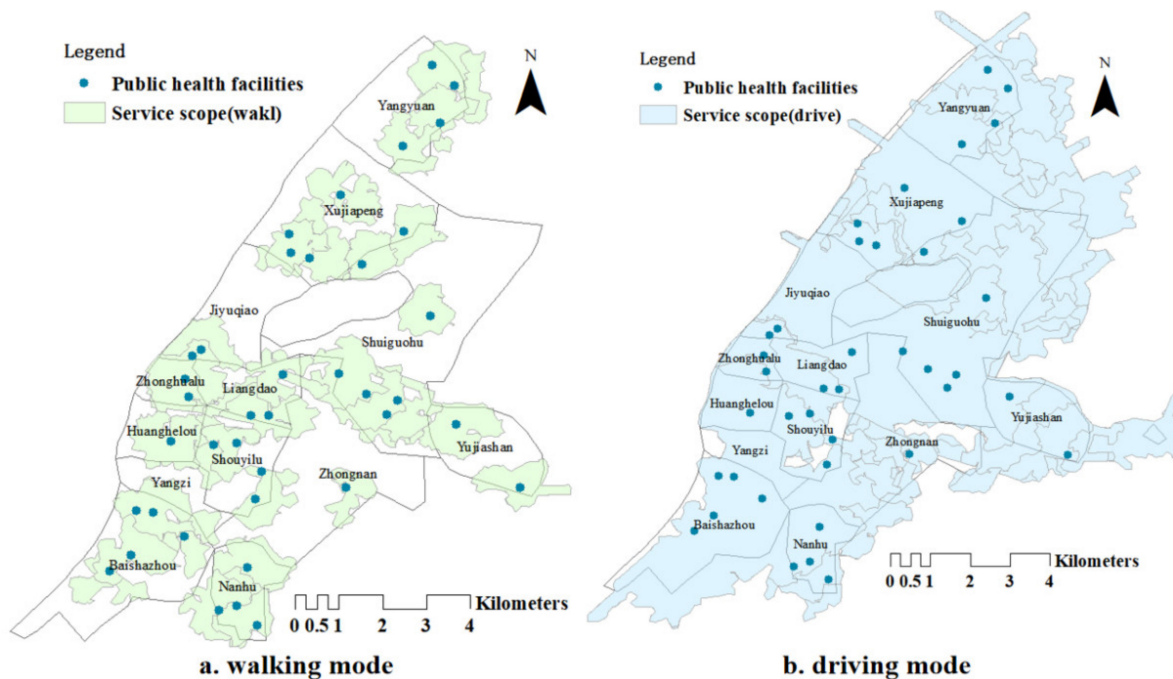


Figure 11. Service area analysis.

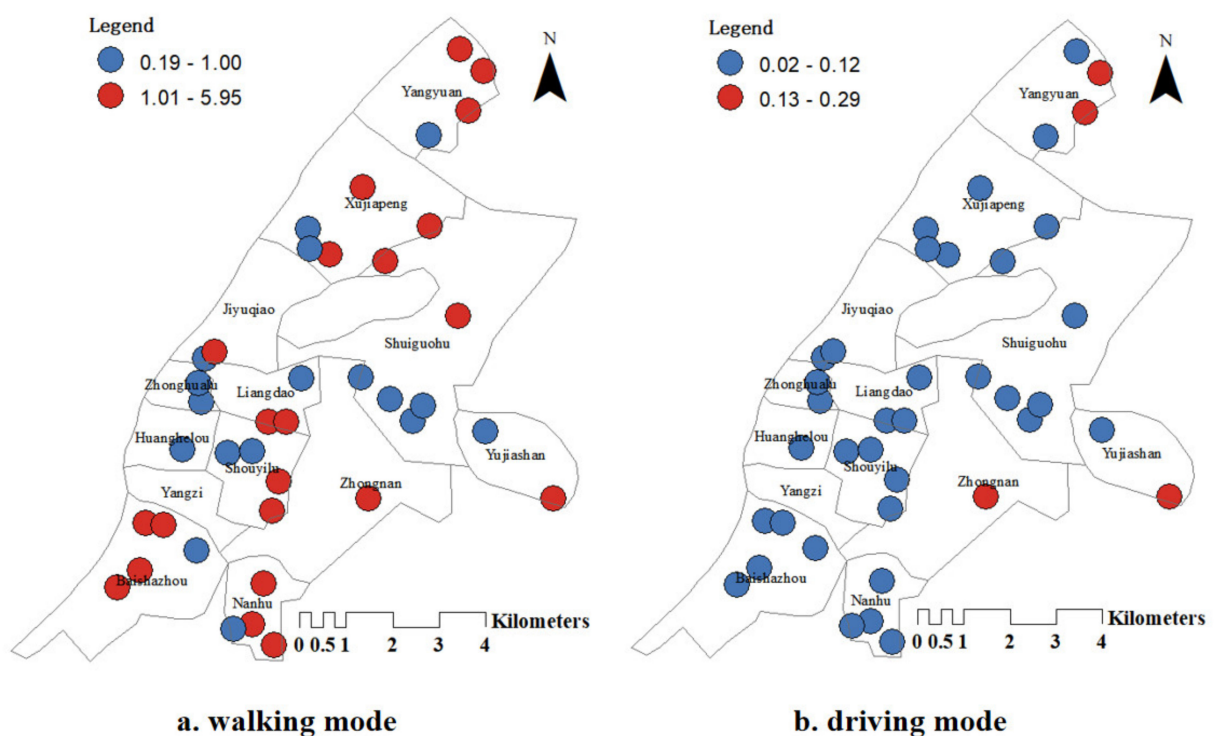


Figure 12. Public health facility service ability.

The calculation results of CA are different under different travel modes. The main reasons are as follows: The service capacity of facilities is greatly affected by the mode of travel. The actual number of people served in the vehicular mode is greater than that in the pedestrian mode; this causes the M_{ij} calculation result to change, and the overall population of CA calculations varies with the distribution of population size.

5.2.2. The Comparison before and after Method Improvement

The traditional average distance method mainly takes the time and space distance as the index of accessibility, calculates the travel cost of all starting points and destination points within the range, and takes the average value as the index of accessibility. This study also uses the average distance method to calculate the A_{ij} value of population data points according to Formula (1), which is also divided into walking and car travel modes (Figure 13). In the case of considering all facilities, the mean value of the walking method was 114.62 min, and the accessibility showed a gradual decline from the center to the periphery. In the vehicle mode, the average value of the calculated results was 19.16 min, showing that the accessibility was lower in the central region and higher in the periphery. The spatial distributions of accessibility indexes of the two computational models are similar, further verifying the effectiveness of the CA model (Figure 14).

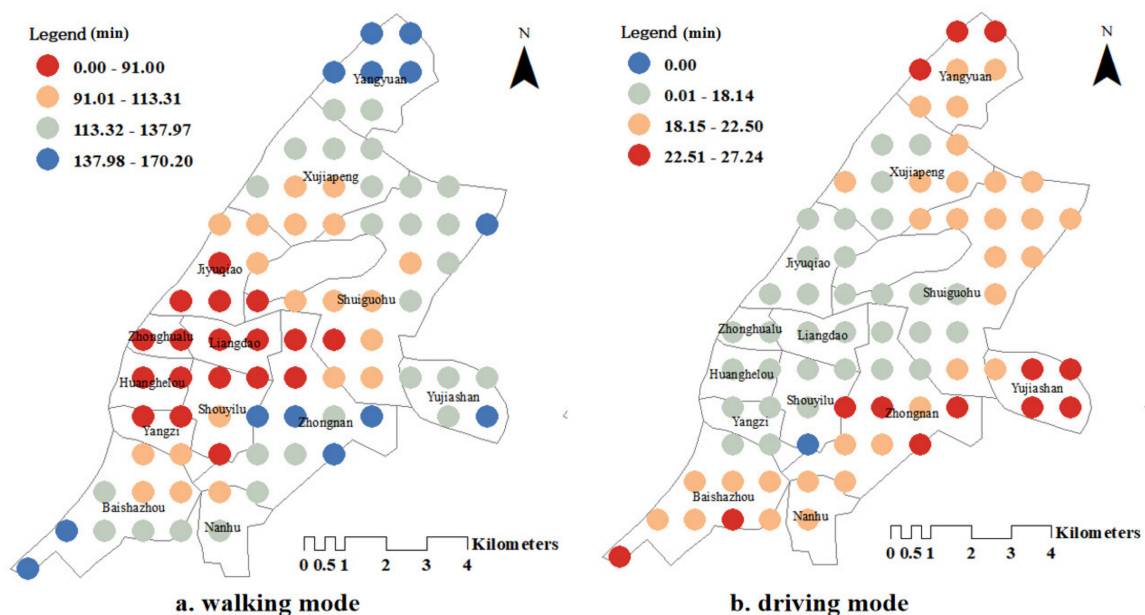


Figure 13. The public health service facility accessibility analysis of each population point by the traditional average distance method.

Compared with the CA index, the calculation result of the average distance method can reflect the time cost value, while the CA index is calculated by considering the influencing factors such as population size, facility service capacity, and resident choice, and the calculated value cannot represent the travel time cost value. The results can only be graded to make a high or low level of accessibility. Compared with the calculation results before and after the model improvement, the distribution of accessibility calculated by the CA method is more scattered than that calculated by the average distance method, and there is no clustering distribution of the same level of accessibility values calculated by the average distance method. This reflects that the factors considered in this research, such as the distribution of community population density, spatial allocation, and service ability of public health facilities, have an impact on the facility accessibility of the community. Compared with the traditional mean distance method, the calculation results of the improved CA model in this study can better reflect the actual situation and guide the spatial layout of facility points in a more refined manner. At the same time, the CA model takes into account the construction standard of the 15 min living circle. The results are consistent with the goal of 15 min life circle construction in urban medical facility planning.

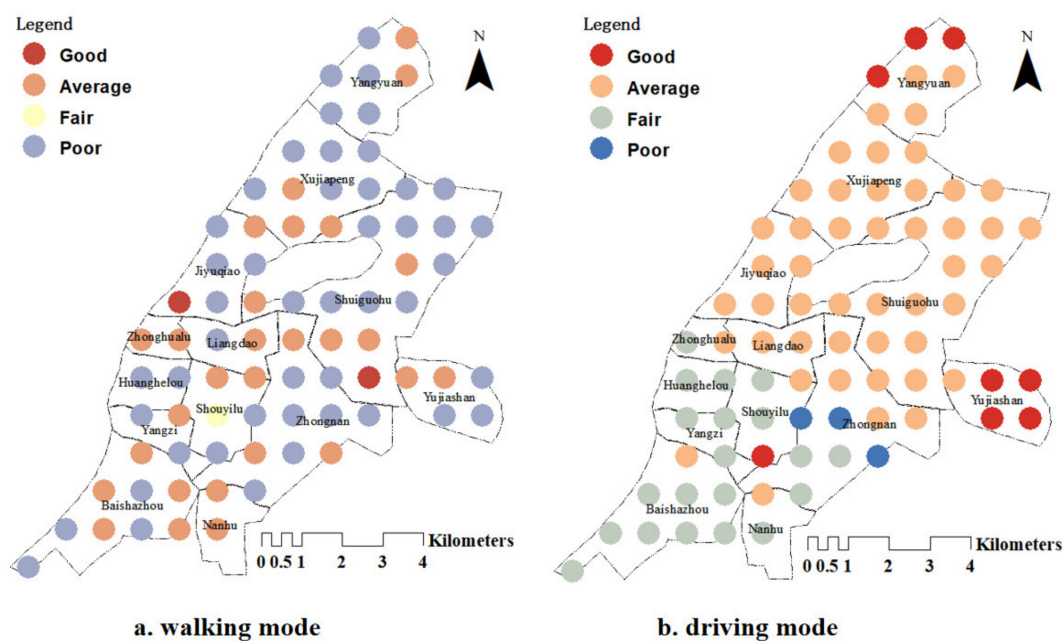


Figure 14. The public health service facility accessibility analysis of each population point by the CA method.

5.2.3. The Promotion Strategies of Accessibility Sink Areas

Lay out facilities based on population distribution to improve service coverage.

Due to the high correlation between the spatial distribution of urban health service facilities and residential communities, the distribution of public health service facilities is selected in combination with the distribution of actual residential population density [42,43]. At the same time, its layout can also channel a part of the resident population and guide the population to areas where the facilities are concentrated. In addition, starting from the needs of people, it is possible to study the demographic structure of each street, and special groups such as children and the elderly have special medical service needs. However, due to the limitations of the data acquisition of this study, the proportion of children and the elderly in the residential population in each research unit in Wuchang District could not be obtained, and it was difficult to propose the spatial allocation planning of medical services for special populations. A previous proposition suggested studying the population structure and allocating special medical and health services in public health service facilities according to actual needs [44]. For Wuchang, this study should focus on improving the public health service facilities in the Zhongnanlu community and Ziyang community, appropriately increasing the number of facilities in combination with the population, improving the coverage level of primary medical and health services in Wuchang, and narrowing the service gap.

Rationally allocate the hierarchical structure of facilities and improve the efficiency of space allocation.

Public health service centers should be planned in areas where residential communities are agglomerated, and public health service stations, as a supplement to public health services, should be evenly distributed as much as possible to respond to major public health emergencies in a timely manner. Most of Wuchang belongs to the old town of Wuhan, large public health service centers are not easy to relocate, and new space resources are few, so the hierarchical structure should be optimized according to local conditions. For areas where there is a concentration of residents who lack public health service centers, local health service stations can be upgraded to improve the level of health services and become public health service centers, or the construction of public health service facilities can be carried out in combination with elderly care facilities, medical care service facilities, and amusement facilities [34]. Combining community management service facilities to increase the number

of public health service stations and to optimize the hierarchical structure of facilities in limited urban resources also promotes the complex development of urban land functions, improves the efficiency of space allocation, and strengthens community resilience.

With the construction of an urban transportation network, the range of space access is improved.

The mechanism of the spatial pattern of accessibility of public service facilities includes the differences in allocation norms, the continuity of population agglomeration, and the accumulation of facility construction [2]. On the basis of ensuring the rational allocation and quantity construction of health service facilities, the layout should be coordinated with the construction of urban transportation networks. Public health service centers should be located near higher-grade roads to facilitate the evacuation of people and reduce traffic congestion, while public health service stations should be evenly arranged deep in residential communities and planned and constructed in combination with slow-moving traffic systems to create a healthy and comfortable travel environment. The small distribution of public health service facilities in Wuchang is one of the reasons for the general accessibility of facilities and also due to the imperfect construction of roads within the community and the discontinuity of the transportation network. Therefore, there is a need to improve the community's broken roads and enhance traffic circulation so as to expand the spatial coverage of public health service facilities.

In order to better optimize the policies related to Wuhan's health planning, this article compares the requirements for public health facility planning in the Wuhan Health Plan (2021–2025) with the recommendations made by this research (Table 3) to serve as a reference for the planning of Wuhan's pandemic medical facilities in the future. The plan formulated by the government mainly addresses the allocation of medical resources in terms of quantity and scale to meet the needs of the population. This paper emphasizes the spatial layout of the facilities, and the suggestions are based on solving the problem from the spatial layout according to the required mathematical research, the number of doctors, beds, medical equipment, etc. At the same time, development strategies are proposed for land resources that can be used in combination with facilities and transportation, improving access and service levels of public health facilities with limited resources. The recommendations made in this article can be referred to in future planning supplements.

Table 3. Comparison between existing strategies and research recommendations.

Planning Strategy	Wuhan Health Plan (2021–2025)	This Research
Space layout	/	The layout of public health service facilities is selected in combination with the actual distribution of residential population density, and new areas have added facilities to channel part of the resident population and guide the distribution of population to areas where facilities are concentrated.
Quantity and scale	One public health service center or station is set up on each street. A neighborhood with a permanent population of more than 100,000 people may set up one additional public health service center or public health service station.	Streets that lack public health services centers can upgrade health service stations or public service facilities to increase the function of health services and promote the development of complex functions of the place of use.

Table 3. Cont.

Planning Strategy	Wuhan Health Plan (2021–2025)	This Research
Resource allocation	Number of beds: dynamically adjusted according to factors such as the population structure of each district, the demand for health services, and the use of existing beds. Medical personnel: public health centers are approved for medical personnel positions according to the population of not more than 16 people/10,000 people. Medical equipment: the service center is equipped with biochemical analyzers, DR, color ultrasounds, and other equipment. Township health centers are equipped with mobile medical and health service vehicles and vehicle-mounted medical equipment.	/
Transportation planning	/	A slow-moving traffic system is planned and built around the facility. Improve the community's broken road and strengthen the traffic microcirculation.

The strategies are all proposed to further build a better urban living environment. However, there will be a number of problems in the actual implementation, such as the economic cost of construction and the benefits of renovating the old city. This is also the limitation of this study, which lacks in-depth research on public policy.

6. Conclusions

As public health service facilities are the fundamental medical and health service facilities in a city, the rationality of their spatial distribution relates to the living quality of every resident and affects the sustainable development of the city's economy and society. A scientific distribution of public health service facilities should make the service radius of different levels of facilities cover people in different areas so as to reduce the time and space costs incurred by residents in the process of obtaining medical and health services. This study proposes a CA index by improving the weighted average distance method. Compared with the weighted average distance, the service capacity of community health facilities and the weight of residents' choice of facilities were considered in this index. Compared with the E2SFCA model, this study uses the standard of 15 min living circle so as to consider the residents' preference for nearby facilities and simplify the calculation of the distance attenuation function in the E2SFCA model. The proposed method can be easily and widely used by urban planning professionals. This paper fully describes the implementation process of CA accessibility analysis to obtain the accessibility index of public health service facilities. At the same time, the important influences of travel impedance, mode of transportation, population size, and service ability of facilities on the public health service facility accessibility of the community were verified. We further discuss the spatial heterogeneity of accessibility. It is concluded that the agglomeration distribution of populations and facilities has a great influence on accessibility. The analysis of the CA model is expected to provide a reference for decision making of rational allocation planning of primary medical service resources. And we explore the sustainable utilization of land resources in the planning of medical facilities and promote the healthy and sustainable development of cities.

An empirical study of the accessibility of public health service facilities in Wuchang District resulted in the following finding: (1) Taking a 15 min walk living circle as the standard, the community-oriented accessibility index of public health service facilities of Wuchang District showed a gradual decline in the middle to sides, and the Zhonghualu community and the Nanhu community had the best accessibility. (2) The calculation results

of CA accessibility in the walking and vehicular modes are quite different, which is mainly affected by the allocation of the number of facilities and the distribution of population. (3) Compared with the method before the improvement, the CA model comprehensively considers various factors such as population size, service capacity of facilities, and construction standards of the 15 min living circle. The calculation results are more reflective of the actual situation and can guide the spatial layout of the facilities more finely. This study also put forward optimization strategies for the main problems existing in the distribution of public health service facilities in Wuchang. In this regard, it is important to highlight the alignment of this paper with the findings of Shen, X. [6], which emphasize enlarging the scale of facilities and increasing the number of doctors and nurses according to population density to meet the medical needs. At present, research related to medical facility planning in Wuhan focuses on urban suburbs or new urban areas, all with the goal of ensuring the equitable and optimal allocation of limited resources [28]. The old city area is where most of the city's population is concentrated, the problems with the configuration of medical facilities are more prominent, and the planning is more complicated. When studying all levels of the medical system together [45], it is easy to ignore the differences in the supply of public medical service facilities. This paper focuses on public health facilities and proposes some spatial optimization layout strategies. Governments and urban planners should pay great attention to the spatial distribution characteristics and correlation intensity of medical resources when formulating relevant policies. In addition, attention should also be paid to the transmission and connection between the planning of medical facilities and road transportation in order to promote the rational distribution and accessibility of public health service facilities in Wuchang District. A contribution that the present research can offer for future works is the possibility of carrying out specific studies of medical facility planning by individual communities of a city. In fact, the division of the district into communities allows a detailed analysis of the accessibility, and, through the model, it allows an understanding of the impact of each factor on the degree of accessibility.

In the future, we will extend this proposed work in the following aspects: (i) In terms of research data, the population data in this paper are based on the population density distribution map, resulting in errors in population accuracy. If more granular population data such as different age groups, genders, and incomes can be obtained, the accessibility of different groups can be further studied. At the same time, if further information on the actual number of visits to public health services can be used as facility scale data, the results may be more effective. (ii) In terms of research methods, this paper sets parameters such as road grade and speed based on the network analysis of the GIS platform according to urban road construction planning standards. In the future, it is necessary to further refine the basic parameter settings of the road network to better simulate the actual situation. At the same time, this paper does not consider the specific impact of special times such as weather and holidays on accessibility, and further detailed analysis is needed. (iii) In terms of research objects, the scope of research in this paper only includes public health facilities, and the scope of research will be expanded in the future to include hospitals, specialized hospitals, etc.

Author Contributions: Conceptualization, H.X.; methodology, H.X. and J.Z.; software, J.Z.; validation, H.X. and J.Z.; formal analysis, J.Z.; investigation, X.Y.; resources, H.X. and J.Z.; data curation, J.Z.; writing—original draft preparation, J.Z.; writing—review and editing, H.X., J.Z. and X.Y.; visualization, J.Z.; supervision, H.X.; project administration, H.X.; funding acquisition, H.X. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by the National Natural Science Foundation of China, grant number 41771473, Hubei Provincial Innovation and Entrepreneurship Training Program for College Students, grant number S202210488071, the Hubei Construction Science and Technology project, grant number [2022]2198-123.

Data Availability Statement: All data and models used during the study appear in the submitted article.

Conflicts of Interest: The authors declare no conflict of interest.

References

- Shmelev, S.E. (Ed.) *Sustainable Cities Reimagined: Multidimensional Assessment and Smart Solutions*; Routledge: London, UK, 2019.
- Huang, J.; Chen, M.; Li, Y.; Peng, M. Evaluation and Optimization of Service Level of Medical and Health Facilities in Wuhan Based on Optimal Path Analysis and Two-step Mobile Search Method. *Mod. Urban Res.* **2019**, *8*, 25–34.
- Luo, Q.; Shu, H.; Zhao, Z.; Qi, R.; Huang, Y. Evaluation of Community Livability Using Gridded Basic Urban Geographical Data—A Case Study of Wuhan. *ISPRS Int. J. Geo-Inf.* **2022**, *11*, 38. [\[CrossRef\]](#)
- Amritpal, K.K.; Victoria, F. Measuring Spatial Accessibility of Healthcare Services in Calgary (poster). *J. Transp. Health* **2017**, *7*, S13–S14.
- Ye, Z.; Li, R.; Wu, J. Dynamic Demand Evaluation of COVID-19 Medical Facilities in Wuhan Based on Public Sentiment. *Int. J. Environ. Res. Public Health* **2022**, *19*, 7045. [\[CrossRef\]](#) [\[PubMed\]](#)
- Shen, X. Accessibility calculation and equality evaluation of medical facilities for COVID-19 pandemic treatment: A case study of the Wuhan metropolitan development zone. *PLoS ONE* **2022**, *17*, e0272458. [\[CrossRef\]](#)
- Van, D.E.; Masseria, C. Income-Related in equalities in the Use of Medical Card in 21OECD Countries. *Health Policy Stud.* **2004**, *14*, 5–28. [\[CrossRef\]](#)
- Ehara, A. Are city population and the number of emergency medical facilities correlated? *Pediatr. Int.* **2009**, *51*, 258–259. [\[CrossRef\]](#)
- Hyun, P.S.; Lee, K. Prediction for the Spatial Distribution of Medical Facilities Complying with the Changes in the Population Structure in Korea. *J. Korean Geogr. Soc.* **2018**, *53*, 371–385.
- Abihiro, G.; Mbera, G.; De, A.M. Gaps in universal health coverage in Malawi: A qualitative study in rural communities. *BMC Health Serv. Res.* **2014**, *14*, 234. [\[CrossRef\]](#)
- Xu, L.; Zhu, X.; Zhu, X.; Miao, H. Research on the configuration of supporting facilities in living circle based on spatial analysis. *Geomat. Spat. Inf. Technol.* **2021**, *44*, 49–51.
- Wu, H.; Wang, L.; Zhang, Z.; Gao, J. Analysis and optimization of 15-minute community life circle based on supply and demand matching: A case study of Shanghai. *PLoS ONE* **2021**, *16*, 8. [\[CrossRef\]](#)
- Guo, Q.; Wang, X.; Li, X.; Ma, H.; Wang, S. Application of Lorenz curve and Gini coefficient in the evaluation of fairness of resource allocation in community health services. *China Health Econ.* **2006**, *25*, 50–53.
- Lin, D.; Liu, K.; Liu, L.; Tan, M. Research on the fairness of health resource allocation in Shenzhen. *Health Soft Sci.* **2020**, *34*, 58–62.
- Javad, J.; Janille, S. Transit Deserts: Equity analysis of public transit accessibility. *J. Transp. Geogr.* **2020**, *89*, 102869.1–102869.9.
- Wang, D.; Qiao, C.; Liu, S.; Wang, C.; Yang, J.; Li, Y.; Huang, P. Assessment of Spatial Accessibility to Residential Care Facilities in 2020 in Guangzhou by Small-Scale Residential Community Data. *Sustainability* **2020**, *12*, 3169. [\[CrossRef\]](#)
- Wang, Y.; Wu, C. Research on the spatial distribution and accessibility of medical institutions in Wuhan based on GIS. *IOP Conf. Ser. Earth Environ.* **2021**, *2*, 825. [\[CrossRef\]](#)
- Sun, C.; Chen, X.; Zhang, H.M.; Huang, Z. An Evaluation Method of Urban Public Transport Facilities Resource Supply Based on Accessibility. *J. Adv. Transp.* **2018**, *2018*, 11. [\[CrossRef\]](#)
- Wang, J.; Zhou, J. Spatial evaluation of the accessibility of public service facilities in Shanghai: A community differentiation perspective. *PLoS ONE* **2022**, *17*, 5. [\[CrossRef\]](#)
- Shivendu, S.S.; Basudatta, S. Cumulative opportunity-based accessibility measurement framework in rural India. *Transp. Policy* **2022**, *117*, 138–151.
- Zang, Y.; Zhao, J.; Li, X.; Feng, Y.; Chen, J.; Wang, F. Research on Layout and Spatial Accessibility of Medical Facilities Based on GIS: A Case Study of Z District of Beijing. *Chin. J. Health Policy* **2021**, *14*, 66–71.
- Luo, J. Research on Accessibility Evaluation and Spatial Planning Strategy of Public Service Facilities in Urban Settlements. Master's Thesis, Zhejiang University, Hangzhou, China, 2019.
- André, N.N.; Apparicio, P. Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal. *BMC Health Serv. Res.* **2011**, *11*, 166.
- Xing, L.; Liu, Y.; Liu, X. Measuring spatial disparity in accessibility with a multi-mode method based on park green spaces classification in Wuhan, China. *Appl. Geogr.* **2018**, *94*, 251–261. [\[CrossRef\]](#)
- Hu, S.; Song, W.; Li, C.; Lu, J. A multi-mode Gaussian-based two-step floating catchment area method for measuring accessibility of urban parks. *Cities* **2020**, *105*, 102815. [\[CrossRef\]](#)
- Salvacion, A.R. Measuring Spatial Accessibility of Healthcare Facilities in Marinduque, Philippines. *ISPRS Int. J. Geo-Inf.* **2022**, *11*, 516. [\[CrossRef\]](#)
- Bhatt, D.; Minal. GIS and Gravity Model-Based Accessibility Measure for Delhi Metro. *Iran. J. Sci. Technol. Trans. Civ. Eng.* **2022**, *46*, 3411–3428. [\[CrossRef\]](#)
- Yang, N.; Chen, S.; Hu, W.; Wu, Z.; Chao, Y. Spatial Distribution Balance Analysis of Hospitals in Wuhan. *Int. J. Environ. Res. Public Health* **2016**, *13*, 971. [\[CrossRef\]](#)

29. Song, Z.; Yan, T.; Ge, Y. Spatial Equilibrium Allocation of Urban Large Public General Hospitals Based on the Welfare Maximization Principle: A Case Study of Nanjing. *China. Sustainability* **2018**, *10*, 3024. [\[CrossRef\]](#)
30. Fu, S.; Liu, Y.; Fang, Y. Measuring the Differences of Public Health Service Facilities and Their Influencing Factors. *Land* **2021**, *10*, 1225. [\[CrossRef\]](#)
31. Chen, Q.; Wang, C.; Lou, G.; Zhang, M.; Wu, S. Measurement of Urban Park Accessibility from the Quasi-Public Goods Perspective. *Sustainability* **2019**, *11*, 4573. [\[CrossRef\]](#)
32. Yaser, E.H.; Mohammad, N.H.; Ammar, A. A multi-criteria approach of assessing public transport accessibility at a strategic level. *J. Transp. Geogr.* **2016**, *57*, 19–34.
33. Tayebbeh, S.; Sara, M.; Russell, G.T. Public transport accessibility in metropolitan areas: A new approach incorporating population density. *J. Transp. Geogr.* **2016**, *54*, 273–285.
34. Li, Z.; Zheng, J.; Zhang, Y. Study on the Layout of 15-Minute Community-Life Circle in Third-Tier Cities Based on POI: Baoding City of Hebei Province. *Engineering* **2019**, *11*, 9. [\[CrossRef\]](#)
35. Chen, H.; Fan, S.; Li, D. Evaluation of the accessibility of basic public service facilities in large-scale affordable housing communities: A case study of Nanjing Daishan affordable housing area. *Constr. Econ.* **2018**, *39*, 81–85.
36. Hyung, M.K.; Kevin, O. Foreign direct investment flows and urban dynamics in a developing country: A case study of Korean activities in Suzhou, China. *Int. Plan. Stud.* **2019**, *24*, 125–139.
37. Hu, D.; Liu, Z.; Hu, W. Congestion Service Facilities Location Problem with Promise of Response Time. *Math. Probl. Eng.* **2013**, *2013*, 11. [\[CrossRef\]](#)
38. Wei, W.; Yang, H.; Tao, Y. Supply and demand matching analysis and planning strategy of community health service facilities from the perspective of “urban people”: A case study of Wuhan. *Mod. Urban Res.* **2020**, *5*, 38–45.
39. George, Y.L.; David, W.W. An adaptive inverse-distance weighting spatial interpolation technique. *Comput. Geosci.* **2008**, *34*, 1044–1055.
40. Conradus, V.M.; Matthias, G.R.F.; David, M. Inhomogeneous interval fields based on scaled inverse distance weighting interpolation. *Comput. Methods Appl. Mech. Eng.* **2021**, *373*, 113542.
41. Liu, R.; Du, M.; Shen, J.; Wang, X.; Jiang, Y. Research on Geriatric Care for Equalizing the Topological Layout of Health Care Infrastructure Networks. *J. Healthc. Eng.* **2021**, *2021*, 13. [\[CrossRef\]](#)
42. Shi, Y.; Yang, J.; Shen, P. Revealing the Correlation between Population Density and the Spatial Distribution of Urban Public Service Facilities with Mobile Phone Data. *ISPRS Int. J. Geo-Inf.* **2020**, *9*, 38. [\[CrossRef\]](#)
43. Mayaud, J.; Tran, M.; Nuttall, R. An urban data framework for assessing equity in cities: Comparing accessibility to healthcare facilities in Cascadia. *Comput. Environ. Urban Syst.* **2019**, *78*, 101401.1–101401.12. [\[CrossRef\]](#)
44. Veser, A.; Sieber, F.; Groß, S.; Prückner, S. The demographic impact on the demand for emergency medical services in the urban and rural regions of Bavaria, 2012–2032. *J. Public Health* **2015**, *23*, 181–188. [\[CrossRef\]](#) [\[PubMed\]](#)
45. Chen, Q.; Cheng, J.; Tu, J. Analysing the global and local spatial associations of medical resources across Wuhan city using POI data. *BMC Health Serv. Res.* **2023**, *23*, 96. [\[CrossRef\]](#) [\[PubMed\]](#)

Disclaimer/Publisher’s Note: The statements, opinions and data contained in all publications are solely those of the individual author(s) and contributor(s) and not of MDPI and/or the editor(s). MDPI and/or the editor(s) disclaim responsibility for any injury to people or property resulting from any ideas, methods, instructions or products referred to in the content.