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Assessing the Spatial Accessibility of Urban Medical Facilities in Multi-Level and Multi-Period Scales Based on Web Mapping API and an Improved Potential Model

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Abstract: Urban medical facilities are an irreplaceable foundation for ensuring higher levels of public health and medical equity. Hospital accessibility has an extremely important impact on the allocation efficiency and fairness of medical facilities. Although critical, previous studies on accessibility have often overlooked the layout of medical facilities at different levels and the accurate measures of travel time to hospitals, which are both the most critical and fundamental indicators when assessing hospital accessibility. To avoid these pitfalls, this study considers the Shijingshan District, Beijing, China, as an empirical case and proposes an improved potential model based on Web Mapping API (Application Programming Interface) to assess the hospital accessibility of hospitals at different levels during different time periods. Results show that there are significant spatial and temporal differences in hospital accessibility in Shijingshan District, and traffic congestion and the layout of medical facilities are the two most important factors affecting hospital accessibility. This study further improves the hospital accessibility assessment method, with the findings provide a spatial decision support system for urban planners and policymakers regarding optimizing the spatial structure and layout of transportation systems and medical facilities.

Keywords: hospital accessibility; improved potential model; web mapping API; medical facility; medical equity

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1. Introduction

Public medical services are an important foundation to ensure the sustainable development of society, and the quality of medical services is directly related to people's health and social equity. The World Health Organization (WHO) points out that the availability of high-quality medical services is an extremely important factor affecting public health and equity [1]. Hospital accessibility is an irreplaceable indicator to assess the quality of public medical services and can affect individuals' healthcare-seeking behavior in many ways [2]. Previous studies proved that the spatial layout of medical facilities has a significant impact on the overall medical service level of a city, and the rational layout of urban medical facilities is of great significance for improving hospital accessibility, ensuring the medical needs of residents, and eliminating spatial polarization [3–5]. At the level of the system structure of medical facilities, many countries have adopted and are still promoting the hierarchical diagnosis and treatment system. Developed countries such as the United Kingdom [6], the United States [7], Germany [8], Finland [9], and Japan [10] have established a relatively clear three-level hierarchical medical service system. According to the different medical needs of residents, different levels of medical facilities provide basic outpatient services, critical and specialist patient diagnosis and treatment services, and refined inpatient medical services. Developing countries, including Brazil [11], India [12], Poland [13], and Thailand [10], have also gradually implemented the initial community diagnosis and grade-by-tier referral system and have constantly paid attention to the construction of a hierarchical medical service system. Medical facilities at different levels have different service capabilities (and scales) and layout requirements, resulting in differences in hospital accessibility. As the largest developing country in the world, China is also in the process of vigorously promoting the reform of its medical services system, establishing a clear hierarchical diagnosis and treatment system, and promoting the provision of "differentiated" medical services by medical facilities at different levels [14]. Therefore, it is particularly important to measure and analyze hospital accessibility based on the layout of medical facilities at different levels and to propose optimization strategies pertinently. In addition, the hospital accessibility research conducted in China can also be used for reference by other countries that also adopt the hierarchical medical service system.

Since the 1980s, China' s urbanization process has accelerated rapidly. By the end of 2020, China's permanent urban population reached 901.99 million, accounting for 63.89% of China's total population. In the meantime, the total number of private car owners reached 226.35 million [15], which is equivalent to one car for every six people. The continuous increase in the population of urban residents has led to an increasing demand for medical treatment in urban areas. With the rapid increase in urban vehicle ownership, self-driving has become one of the irreplaceable travel modes for urban residents to seek medical treatment. Hospital accessibility under a self-driving travel mode directly affects the timeliness and quality of medical treatment.

Accessibility can be defined and understood in various ways, and one of the most widely accepted definitions is "the interaction of opportunity potential" [16]. Hospital accessibility includes both spatial and non-spatial indicators [17,18]; it can be defined as the possibility and difficulty with which residents can reach a medical facility by different means of transportation [19,20]. Hospital accessibility is regarded as a basic indicator for evaluating the rationality of the allocation of urban medical facilities, and achieving better hospital accessibility has also become an important aspect to improve the quality of urban medical services and optimize the layout of urban medical facilities [21–23].

Scholars applied multiple models to assess hospital accessibility, and the most commonly accepted methods include the distance to the nearest provider [24], the population-to-provider ratio (PPR) [25], the kernel density method [26,27], and the potential model (or gravity model) [16,28–30]. Benefiting from the maturity and continuous improvement of Geographic Information System (GIS) technology, many methods developed based on the potential model have been introduced to assess hospital accessibility, among which the two-step floating catchment area (2SFCA) method is the most widely used [31–33]. Recently, several rectifications and replenishments to the 2SFCA method have been proposed in order to overcome limitations of the 2SFCA method, including the three-step floating catchment area (3SFCA) method [34], the gravity 2SFCA (G2SFCA) method [35], the Gauss 2SFCA (Ga2SFCA) method [36], the dynamic Huff 2SFCA (DH2SFCA) method [37], the enhanced two-step floating catchment area (E2SFCA) method [38], the hierarchical 2SFCA (H2SFCA) method [39], and the kernel density 2SFCA (KD2SFCA) method [40,41].

Compared with other methods, the potential model more intuitively reflects the spatial competition between facility suppliers and demanders, and it has a more complete and clearer concept and more flexible usages [25,42]. The potential model assumes a negative correlation between the residents' hospital accessibility and the distance from surrounding medical facilities, which fully considers the impact of distance decay effects on hospital accessibility, and it can also more accurately capture the characteristics of supply and demand [43,44]. However, the existing methods fail to adequately take into account the spatial layout of medical facilities at different levels and the accurate acquisition of the travel time to hospitals, which are both indispensable indicators when assessing hospital accessibility [45]. To avoid such pitfalls, it is necessary to adopt a more accurate method of time and travel data collection, such as the Web Mapping API (Application Programming Interface) [46].

With the rapid development and in-depth application of big data technology, online map navigation technology has developed rapidly [47]. When using online map navigation technology for traffic route planning, it is possible to calculate the big data of road networks and the number of vehicles, analyze the traffic congestion situation, and measure the real-time travel speed, so as to achieve the accurate prediction of accessibility travel times. Online Web Mapping API provides a simple and convenient way to apply online map navigation technology to accessibility research [48,49]. Web Mapping API encapsulates most of the underlying technical details, and users only need to write a python program to connect to the provided program interface online to achieve the desired acquisition. Global mainstream online map operators such as Google Maps, Bing Maps, Yahoo Maps, Baidu Maps, and Gaode Maps all provide their own Web Mapping API platforms. Many studies on accessibility have begun to fully apply Web Mapping API technology, such as measurements of urban walking accessibility [50], measurements of general travel accessibility [51], measurements of park accessibility [37,47,52,53], and the measurement of hospital accessibility [38,45,54,55]

To sum up, this study takes Shijingshan District, Beijing, China, as an empirical case. Based on the real-time traffic data obtained through the Gaode Map API platform, an improved potential model was used to analyze hospital accessibility at different time periods and different levels of medical facilities. This improves the consistency between hospital accessibility measurements and actual traffic conditions, further expands and optimizes methods for assessing hospital accessibility, and provides recommendations for the spatial layout optimization of urban infrastructure, especially medical facilities.

2. Methods

Residents' healthcare seeking behaviors can be broadly divided into two types [18]: (1) emergency medical treatment, that is, medical treatment for critical diseases, acute diseases or accidents and emergencies. This type of behavior strongly emphasizes the timeliness of medical treatment, and the accessibility travel time is the most significant factor affecting hospital accessibility under this pattern. (2) Ordinary (or daily) medical treatment, that is, the medical treatment behavior of non-acute diseases. Under this pattern, alongside the timeliness of medical treatment, the level, scale, and quality of medical facilities are also important factors affecting hospital accessibility. In addition, the spatial differentiation of population density also has a great impact on the spatial distribution characteristics of hospital accessibility [56]. Therefore, this study analyzes hospital accessibility from two perspectives: the hospital accessibility travel time and the comprehensive hospital accessibility. An overview of the methods workflow is illustrated in Figure 1.

2.1. Assessing the Hospital Accessibility Travel Time

Using the online map navigation service to construct isochronous circles of accessibility at different time periods can accurately reflect the spatial differentiation of the hospital accessibility travel time. The isochronous circle mentioned in this study refers to the spatial boundary formed when starting from a certain point, according to the selected mode of transportation and within a specified time, through the online map for route planning to a designated place. According to the "2020 Beijing Transportation Development Annual Report", the average speed of vehicles in Beijing during peak periods is 450 m/min [57]. Therefore, in this study, the research area is divided into 500m $\times$ 500m grid lattices in order to control the time assessment error. By writing python algorithm programs and linking the Gaode Map API interface, batch interaction with online maps is realized. Through the route planning module of the Gaode Map API, the shortest travel time for each lattice to reach all medical facilities in the corresponding travel mode is automatically calculated. The obtained time data were cleaned, filtered, and counted, and the IDW (Inverse Distance Weighted) tool in the ArcGIS platform was used to calculate and visualize the hospital accessibility travel time (Figure 2).

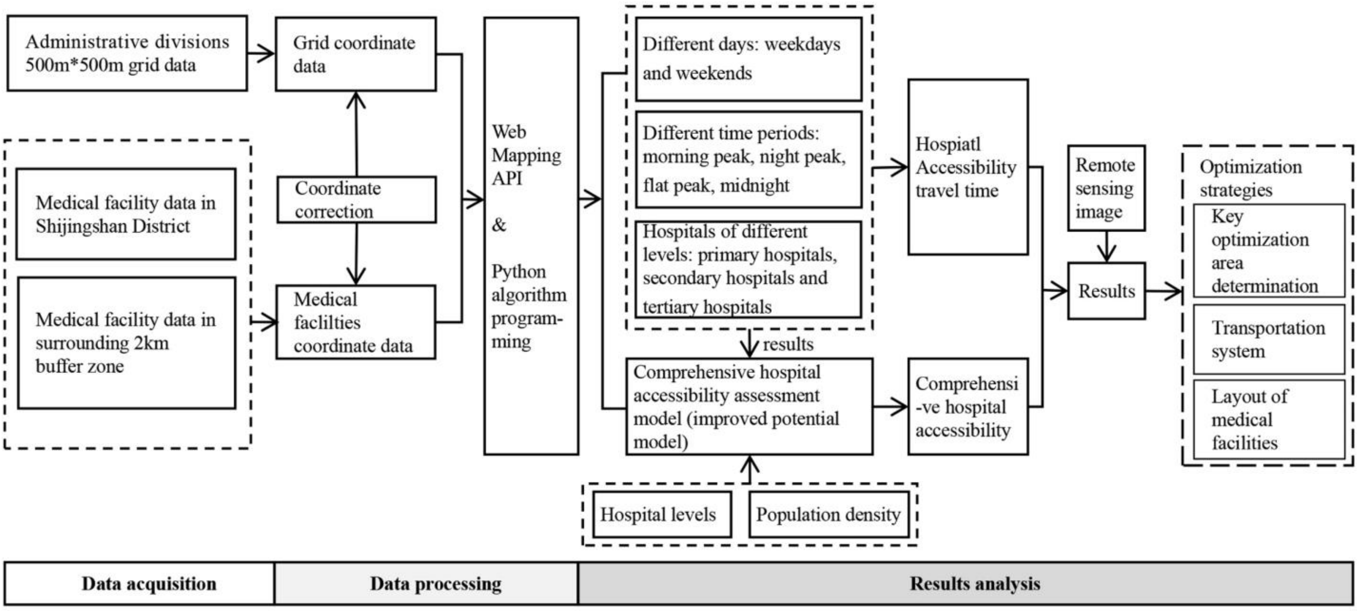

Figure 1. Methods workflow.

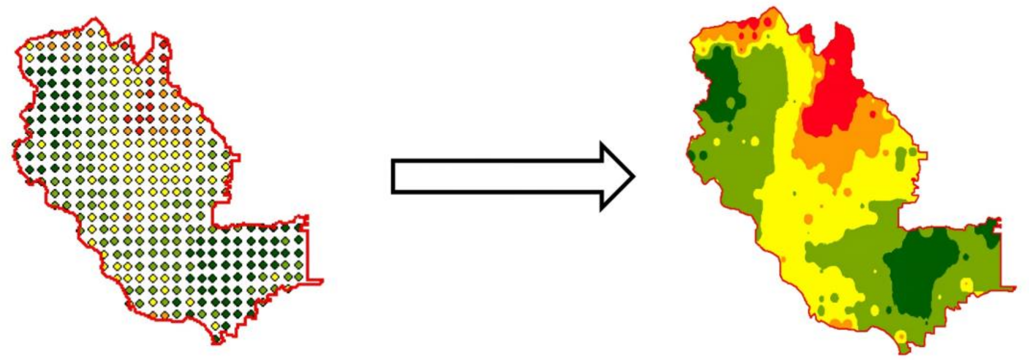

Figure 2. Construction of the isochronous circle and visualization of hospital accessibility travel times.

2.2. *Potential Model and Its Improvement*

The potential model has been broadly employed to assess the spatial accessibility of urban medical facilities while considering the distance decay, spatial barrier, and the scale of medical facilities [54]. The basic potential model is as follows:

$$A_y = \sum_{x=1}^{n} A_{xy} = \sum_{x=1}^{n} \frac{M_x}{D_{xy}^{\beta}} \quad (1)$$

where A_y is the hospital accessibility in area y and the comprehensive potential created by all medical facilities in the study area to area y; A_{xy} denotes the gravity created by hospital x to area y while the friction coefficient is β, which describes travel impedance; M_x stands for the scale of hospital x; and D_{xy} denotes travel impedance from area y to hospital x.

The basic potential model fails to fully consider the effect of the population density radiated by hospitals at different levels and its impact on hospital accessibility. In order to avoid this pitfall, the population size factor V_i is introduced [58], and then an Improved Potential Model is formed. This improved model is as follows:

$$A_y = \sum_{x=1}^{n} A_{xy} = \sum_{x=1}^{n} \frac{M_x}{D_{xy}^{\beta} V_i}, V_i = \sum_{k=1}^{m} \frac{P_k}{D_{ki}^{\beta}} \quad (2)$$

where n and m stand for the number of hospitals and residential areas, respectively, and P_k represents the population of the residential area k.

According to China's "Third-level Hospital Evaluation Standards (2020 Edition)" [59], this study classified hospitals into to three levels: tertiary hospitals, secondary hospitals, and primary hospitals. Referring to the weight assignments for hospitals of different levels in previous studies [60,61], this study determined that the weight values of tertiary, secondary, and primary hospitals were 60, 30, and 10, respectively. The comprehensive hospital accessibility assessment model based on the improved potential model used in this study is as follows:

$$A_y = \sum_{x=1}^{3} \frac{M_x}{D_{xy}^{\beta} V_i}, V_i = \sum_{k=1}^{m} \frac{P_k}{D_{ki}^{\beta}} \quad (3)$$

where A_y denotes the comprehensive hospital accessibility of area y, and the numerical value of A_y is positively correlated with the comprehensive hospital accessibility of the residential area; x is the hospital closest to the location y, and there are three hospitals in total, one for each of the tertiary, secondary, and primary hospitals. This study assumes that under the premise of having the same level of hospitals, residents will prefer the nearest hospital for medical treatment, so there is only one hospital of each level in the model assessment. M_x is the weight value of hospital x; D_{xy} denotes the travel impedance, which specifically refers to the optimal travel time from the residential area y to the nearest hospital x by self-driving; the optimal travel time is obtained by calculating the average hospital accessibility travel time in three periods: a morning peak, evening peak, and flat peak period, and the measurement unit is minute. β represents the friction coefficient; the larger the value of β, the more obvious the reduction effect of the accessibility travel time on comprehensive hospital accessibility.

3. Study Area and Data Sources

3.1. Overview of the Study Area

Shijingshan District is located in the west of Beijing, about 14 km away from the center of Beijing city (Tiananmen Square). The area is about 12.25 km wide from west to east and 13 km long from south to north, with a total area of 85.74 square kilometers [62]. Shijingshan district is one of the six main urban areas of Beijing, and also one of the four urban functional expansion areas of Beijing. Shijingshan district comprises nine subdistricts, including Babaoshan Subdistrict, Laoshan Subdistrict, Bajiao Subdistrict, Gucheng Subdistrict, Pingguoyuan Subdistrict, Jinding Subdistrict, Guangning Subdistrict, Wulituo Subdistrict, and Lugu Subdistrict. As of November 2020, the resident population of Shijingshan District was 567,851 [63].

Regarding land use types, the eastern and southern parts of Shijingshan District have the most residential areas, complex community networks, and a high population density. Regarding the distribution of medical facilities, there are nine hospitals in Shijingshan District, including one tertiary hospital, four secondary hospitals, and four primary hospitals. Regarding the regional public transportation system, only two subway lines pass through Shijingshan District, namely, Metro Line 1 and Line 6. Due to the lack of subway and bus lines, most residents in Shijingshan District use motor vehicles to travel, and the huge number of vehicles has brought great pressure to the regional transportation system. According to the 2021 comprehensive traffic data released by the Beijing Municipal Commission of Transportation [64], among the six main urban areas in Beijing, Shijingshan District was the one with the highest increase in the traffic congestion index. Traffic congestion has brought serious challenges to the timeliness of residents' self-driving medical treatment. It is urgent to analyze the impact of traffic congestion on hospital accessibility in Shijingshan District and to propose targeted optimization strategies.

3.2. Data

Considering that seeking medical treatment nearby and going to a higher-level hospital for medical treatment are two healthcare-seeking behaviors that exist in reality, the hospital information data selected in this study not only include hospitals in Shijingshan District, but also hospitals within the 2 km buffer zone around Shijingshan District (considering that the average radius of Shijingshan District is about 2 km, the standard for buffer zone delineation is determined to be 2 km). The specific hospital information was collected from the Beijing Municipal Government Affairs Data Resource Network [65]. A total of 20 nonprofit general hospitals was selected, including 9 in Shijingshan District, 7 in Mentougou District, and 4 in Haidian District. Hospital grading and classification refer to the relevant standards in the "Third-level Hospital Evaluation Standards (2020 Edition)" [59]. The population data selected in this study are from the "Seventh National Census Bulletin of Shijingshan District, Beijing" [63], including the permanent population, population density, and other information, and the residential area data were provided by the Beijing City Lab [66]. The visualization of the population density and hospital spatial distribution in the study area is shown in Figure 3.

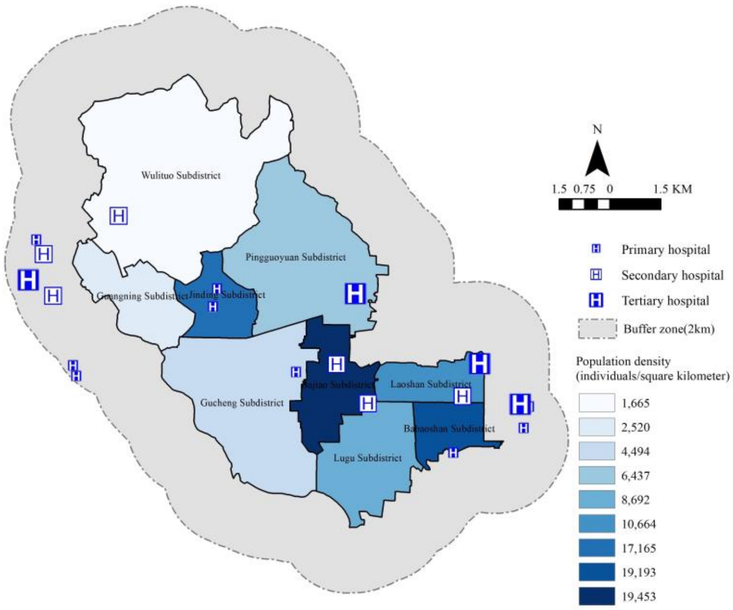

Figure 3. Population density and hospital distribution in the study area.

In this study, we chose to collect data for multiple days to obtain the average value to avoid the possible interference and inaccuracy of data collected on a specific single day. The data collection time is midnight on 2 March 2022, and the morning peak, evening peak, and flat peak periods are from 6–14 March 2022. The specific time period is defined as: morning peak from 6:00–8:30 a.m., evening peak from 5:30–8 p.m., midnight from 0–4 a.m., and flat peak from 10–12 a.m. or 3–5 p.m. It should be noted that this study selected the midnight period as the control group to analyze and compare the changes in hospital accessibility in different time periods and in different regions without traffic congestion. Therefore, the calculation of the average hospital accessibility travel time in this study only includes the data of three time periods: the morning peak, the flat peak, and the evening peak.

4. Results

4.1. Analysis of Hospital Accessibility Travel Time

4.1.1. Analysis of Hospital Accessibility Travel Time on Weekdays and Weekends

In this study, the traffic travel data obtained through the Web Mapping API was used to calculate the hospital accessibility travel time during different time periods on weekdays and weekends, and the calculated average values are shown in Figure 4. On weekdays, the average accessibility travel time of the tertiary, secondary, and primary hospitals was 17.95 min, 11.44 min, and 12.27 min, respectively; on weekends, the accessibility travel time of the tertiary, secondary, and primary hospitals was 16.32 min, 10.58 min, and 11.41 min, respectively. The accessibility travel time of hospitals of different levels in Shijingshan District shows the same characteristics on weekdays and weekends: the hospital accessibility travel time of secondary hospitals is the shortest, and the accessibility travel time of tertiary hospitals is the longest. In Shijingshan District, the difference between the average hospital accessibility travel time on weekends and weekdays is not obvious, and the hospital accessibility travel time values of weekends are generally shorter than those of weekdays.

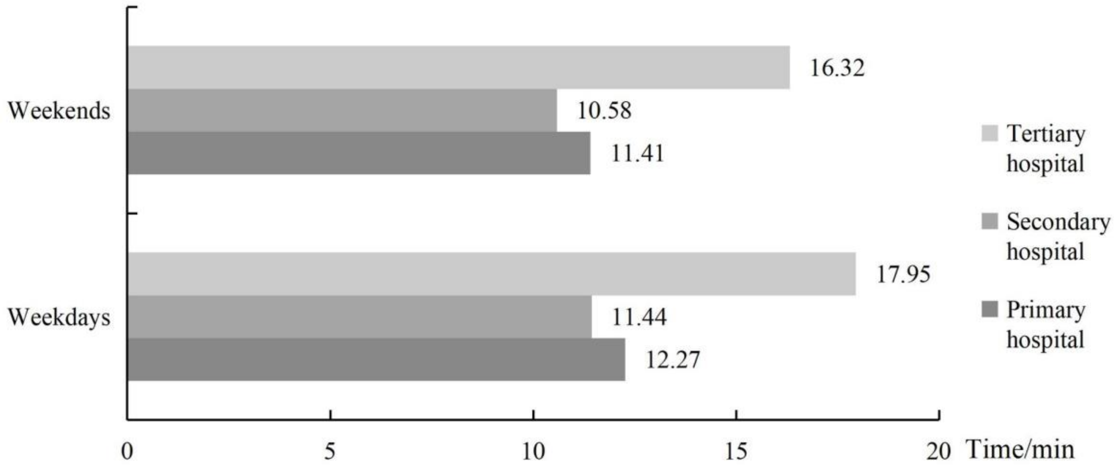

Figure 4. Average hospital accessibility travel time on weekends and weekdays.

4.1.2. Analysis of Hospital Accessibility Travel Time in Different Time Periods

The accessibility travel times of hospitals at all levels in Shijingshan District at different time periods on weekdays have the following characteristics (Figure 5): (1) hospitals at all levels have the longest accessibility travel time during morning peak period and the shortest during flat perk period, and there is little difference between the accessibility travel time during the flat peak period and the evening peak period; (2) for hospitals of the same level, due to the impact of traffic congestion, the accessibility travel time during the morning, evening, and flat peak periods is 27.15% longer on average than the accessibility travel time at the midnight period (i.e., the period without traffic congestion); (3) for hospitals at different levels, the accessibility travel time of tertiary hospitals is the longest in all time periods. The average accessibility travel time of tertiary hospitals in all time periods was 17.95, which was 5.68 min and 6.51 min longer than the average accessibility travel time of primary and secondary hospitals, respectively, while the average accessibility travel time of primary hospitals was only 0.83 min longer than that of secondary hospitals.

The accessibility travel time of hospitals at all levels in Shijingshan District at different time periods on weekends have the following characteristics (Figure 6): (1) contrary to weekdays, hospitals at all levels have the shortest accessibility travel time during the morning peak period and the longest during the flat peak period, but the difference in the accessibility travel time between the morning, evening, and flat peaks is not obvious, indicating that the influence of traffic factors on the accessibility travel time on weekends is not as significant as on weekdays; (2) for hospitals at the same level, the average accessibility travel time during the morning, evening, and flat peak periods is generally shorter than those on weekdays; (3) similar to weekdays, for hospitals at different levels, the accessibility travel time of tertiary hospitals is the longest in all time periods.

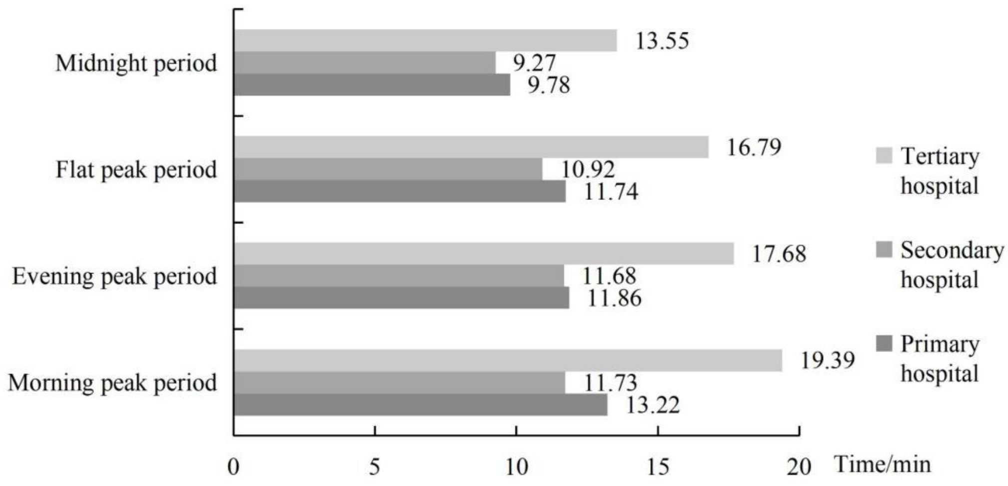

Figure 5. Hospital accessibility travel time in different time periods on weekdays.

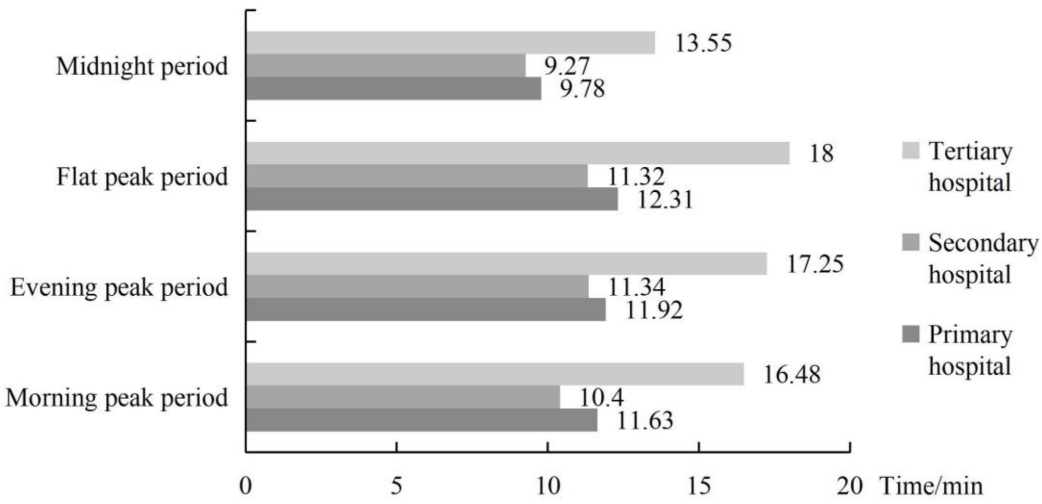

Figure 6. Hospital accessibility travel time in different time periods on weekends.

4.2. Analysis of Comprehensive Hospital Accessibility

4.2.1. Determination of Friction Coefficient

The application of the friction coefficient β improves the accuracy of the potential model's measurement, and the value of β should have different ranges under different circumstances [67]. Empirical studies on the appropriate value range of friction coefficient β in different situations have been carried out extensively. Peeters and Thomas founded that the value of β is mainly concentrated in the range of 0.9 to 2.29, and when the value of β is between 1.5 to 2, it has little effect on the final calculation result [68]. In an empirical study of commuting patterns in Chicago, Wang founded that the optimal value of β was 1.85 [69]. Tao determined that $\beta = 1$ in research on the accessibility of public medical services in Haizhu District, Guangzhou, China [70]. Wu determined that $\beta = 2$ in a study on the accessibility of rural medical facilities in Lankao County, Henan Province, China [71]. Wang and Song found that the value range of β is mostly concentrated between 1 and 2, but its specific value should be calibrated according to the characteristics of the study area [18,72]. In view of the above, the value of the friction coefficient β should be determined according to the specific conditions of the research area in the comparative analysis of pre-experiment results.

In order to scientifically determine the value of the friction coefficient β, this study selected the morning peak period for the pre-experiment and determined the value of β as 1 and 2, respectively, obtaining different results for comprehensive hospital accessibility under the two values. Pre-experimental results show that the standard deviation of comprehensive hospital accessibility is 14.51 when $\beta = 1$, while the standard deviation of comprehensive hospital accessibility is 4.20 when $\beta = 2$. When $\beta = 2$, the proportion of regions with a comprehensive hospital accessibility index of 10 is 96.14%, and the proportion of regions with a comprehensive hospital accessibility index of 5 is 91.69%, indicating that when $\beta = 2$, the correlation data are excessively concentrated and the polarization of analysis results is serious, which cannot fully reveal the comprehensive hospital accessibility between regions. When $\beta = 1$, the discrete degree of accessibility values is higher, which can better reflect the spatial differentiation degree of comprehensive hospital accessibility in Shijingshan District. In addition, the IDW tool of the ArcGIS platform was used to present spatial visualization analysis on the comprehensive hospital accessibility under the two β values (Figure 7), and the step sizes were set to 5 and 10 for hierarchical analysis. The results show that when $\beta = 1$, it can more accurately reflect the spatial distribution differences of comprehensive hospital accessibility in different areas of Shijingshan District. Therefore, in this study, the value of friction coefficient β is taken as 1 to analyze the comprehensive hospital accessibility of Shijingshan District.

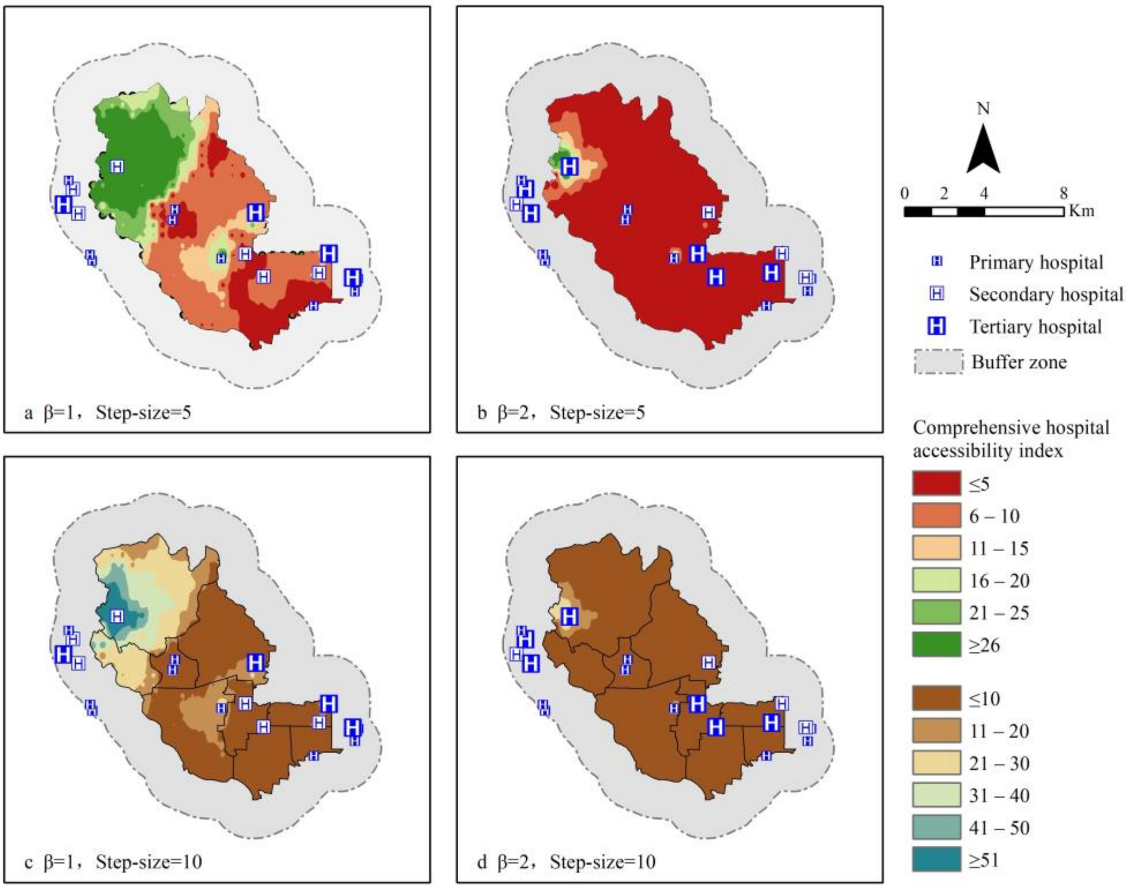

Figure 7. Comprehensive hospital accessibility under different friction coefficient β values.

4.2.2. Analysis of Comprehensive Hospital Accessibility on Weekdays

Based on formula (3), this study calculates the hospital accessibility of three-level hospitals in Shijingshan District on weekdays, and superimposes the calculation to generate the comprehensive hospital accessibility spatial pattern of Shijingshan District on weekdays. Previous studies mostly divide hospital accessibility into 5 [73] or 6 [60,74] levels for further assessment based on specific analysis results. Based on the calculation results for comprehensive hospital accessibility in Shijingshan District, this study determined the step size as 5 and divided the comprehensive hospital accessibility into six levels for comparative analysis. The visualization results of the comprehensive hospital accessibility classification on weekdays are shown in Figure 8.

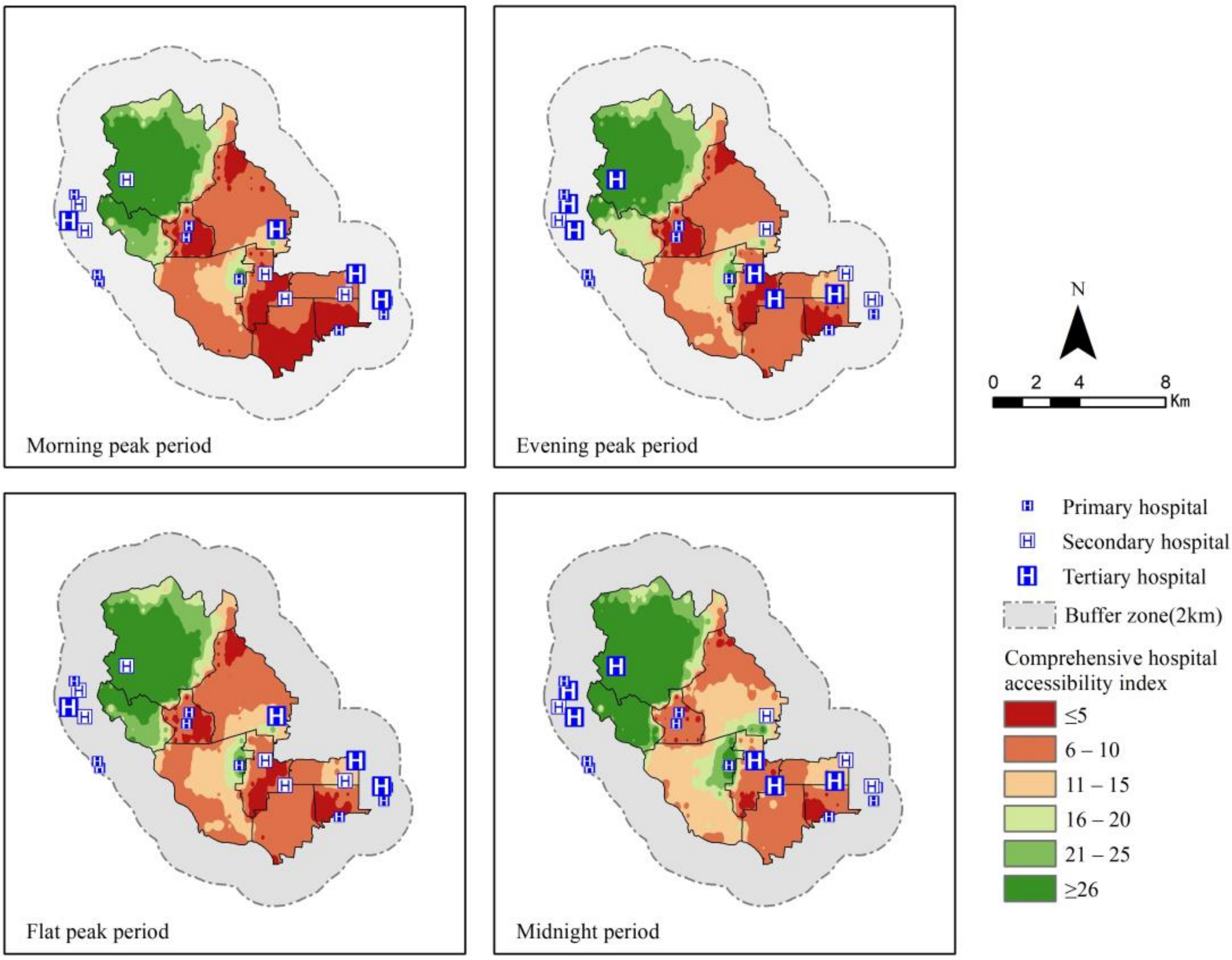

Figure 8. Comprehensive hospital accessibility on weekdays.

The comprehensive hospital accessibility of Shijingshan District at different time periods on weekdays is ranked as follows: (1) midnight period; (2) flat peak period; (3) evening peak period; (4) morning peak period. The comprehensive hospital accessibility of the midnight period is the best and is significantly better than the other three periods; the comprehensive hospital accessibility of the morning peak period is the worst, and the gap between that of the evening peak and flat peak period is not obvious. The comprehensive hospital accessibility of Shijingshan District on weekdays shows clear spatial differentiation and aggregation characteristics: Wulituo Subdistrict and Guangning Subdistrict in the northeast of Shijingshan District have the best comprehensive hospital accessibility. Extending outward from these two subdistricts, the comprehensive hospital accessibility exhibits a gradual decay characteristic: Pingguoyuan Subdistrict, Lugu Subdistrict, Bajiao Subdistrict, and Babaoshan Subdistrict in the central and southern areas of Shijingshan District have the worst comprehensive hospital accessibility.

4.2.3. Analysis of Comprehensive Hospital Accessibility on Weekends

Through the above methods, the comprehensive hospital accessibility on weekends is classified, analyzed, and visualized, and the results are shown in Figure 9. The comprehensive hospital accessibility of Shijingshan District at different time periods on weekends is ranked as follows: (1) midnight period; (2) flat peak period; (3) morning peak period; (4) evening peak period. Except for the midnight period, which is not affected by traffic congestion, the flat peak period is still the period with the best comprehensive hospital accessibility, and the comprehensive hospital accessibility of the morning peak period is slightly better than that of the evening peak period. Compared with weekdays, the spatial pattern of comprehensive hospital accessibility on weekends generally presents similar characteristics, and the comprehensive hospital accessibility in the northwest area is still significantly better than that in the southeast area, while the areas with poor comprehensive hospital accessibility are decreased.

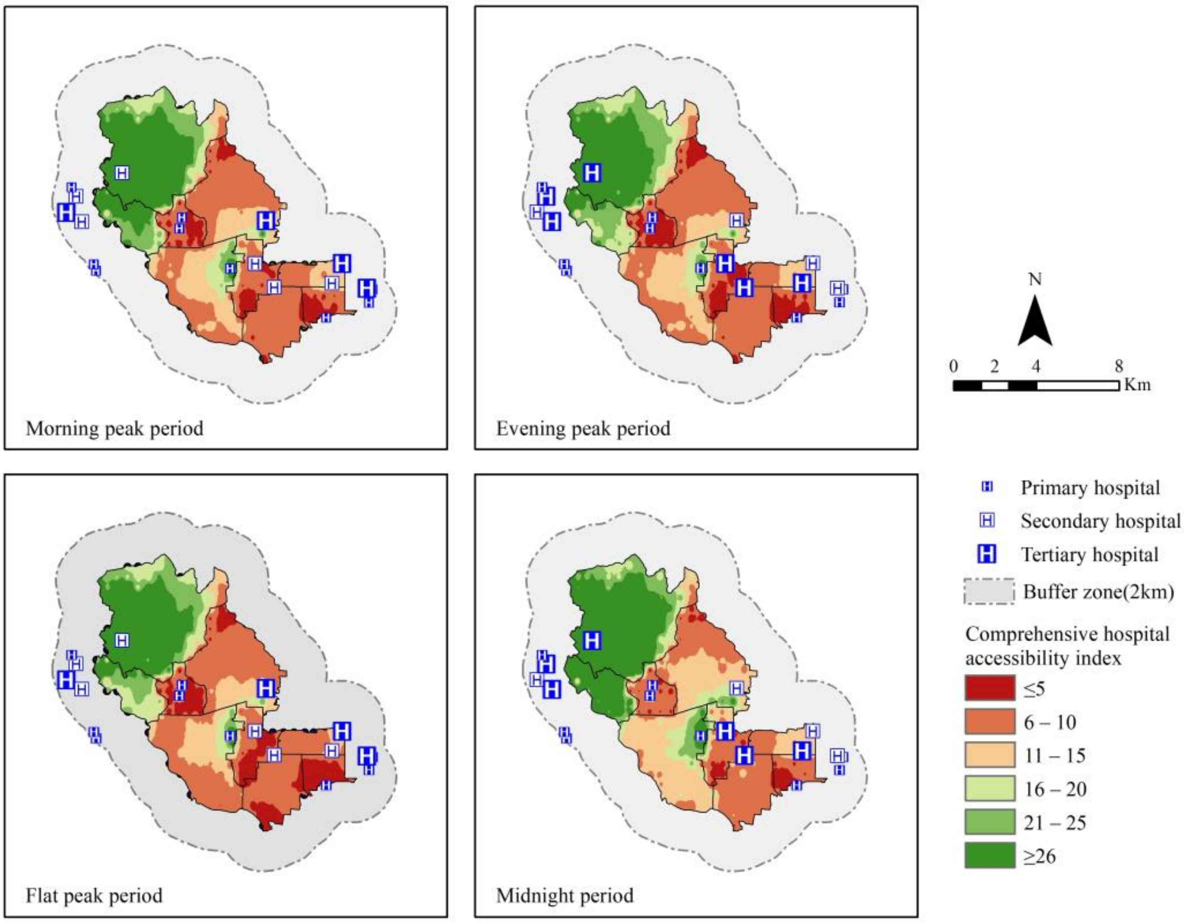

Figure 9. Comprehensive hospital accessibility on weekends.

4.3. Identification of Key Optimization Areas and Optimization Strategies

4.3.1. Identification of Key Areas for Transportation Optimization

From the analysis in the previous chapters, it can be seen that the traffic congestion in Shijingshan District is the most serious on weekdays, and the impact of traffic congestion on hospital accessibility is most significant on weekdays. Therefore, this study compares and analyzes the comprehensive hospital accessibility of self-driving mode in Shijingshan District on weekdays and the comprehensive hospital accessibility at the midnight period (i.e., the period without traffic congestion) and obtains the comprehensive hospital accessibility change difference value based on traffic congestion factors, and combined with the residential area data in Shijingshan District, the IDW tool of the ArcGIS platform is used to identify and visualize the key areas of transportation optimization (Figure 10). The results show that under the influence of traffic congestion, the comprehensive hospital accessibility index of each area in Shijingshan District decreased to varying degrees.

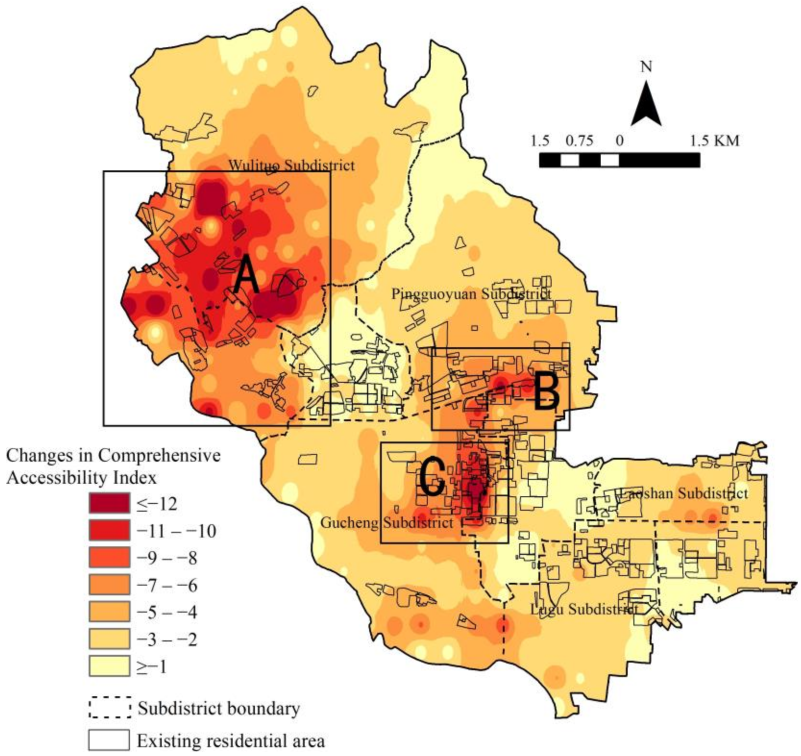

Figure 10. The key areas of transportation optimization in Shijingshan District.

Under the influence of traffic congestion, the areas with the most significant decrease in the comprehensive hospital accessibility index (a decrease of 10 and above) are marked as Area A, Area B, and Area C in Figure 10. Combined with the remote sensing and street view images obtained from Baidu Maps, this study analyzes the above-mentioned key areas for transportation optimization from two aspects: land use category and traffic system quality. (1) Area A is the south of Wulituo Subdistrict and the north of Guangning Subdistrict. This area is densely distributed, with a large number of residential areas and educational facilities such as primary schools and kindergartens. The roads in the area are relatively narrow, and commuting to work and school is the main factor causing traffic congestion. (2) Area B is the southern part of Pingguoyuan Subdistrict, where residential, commercial, educational, medical, and other land use types are mixed, and the phenomenon of mixed traffic and illegal parking is serious. The peak periods of various travel modes are superimposed on each other, which aggravates the impact of traffic congestion on the comprehensive hospital accessibility. (3) Area C is the northeastern part of Gucheng Subdistrict. The roads in the area are of poor quality, and the infrastructure is relatively old, which further aggravates traffic congestion.

4.3.2. Identification of Key Areas for Medical Facility Layout Optimization

The determination of key areas for the optimization of the layout of medical facilities in Shijingshan District is based on the analysis of the spatial distribution pattern of comprehensive hospital accessibility for self-driving travel mode. In order to decrease the influence of traffic congestion factors, this study selects the spatial distribution pattern of comprehensive hospital accessibility at midnight on weekdays and weekends, and based on the spatial distribution data of hospitals and residential areas, the IDW tool of the ArcGIS platform is used for analysis and visualization (Figure 11). Under the influence of the spatial distribution pattern of hospitals and residential areas, the areas with the most significant decrease in the comprehensive hospital accessibility index are marked as Area A, Area B, and Area C in Figure 11. Area A is Babaoshan Subdistrict, and Area B is Bajiao Subdistrict. There are a large number of existing residential areas in these two areas, and many new residential areas are planned. The quantity and quality of existing medical facilities in the two areas cannot meet the residents' growing medical needs. Area C is the north of Pingguoyuan Subdistrict. This area is mainly composed of mountains, forests, and parks. There are few residential areas in the area, and there are also few supporting medical facilities in the area and adjacent areas.

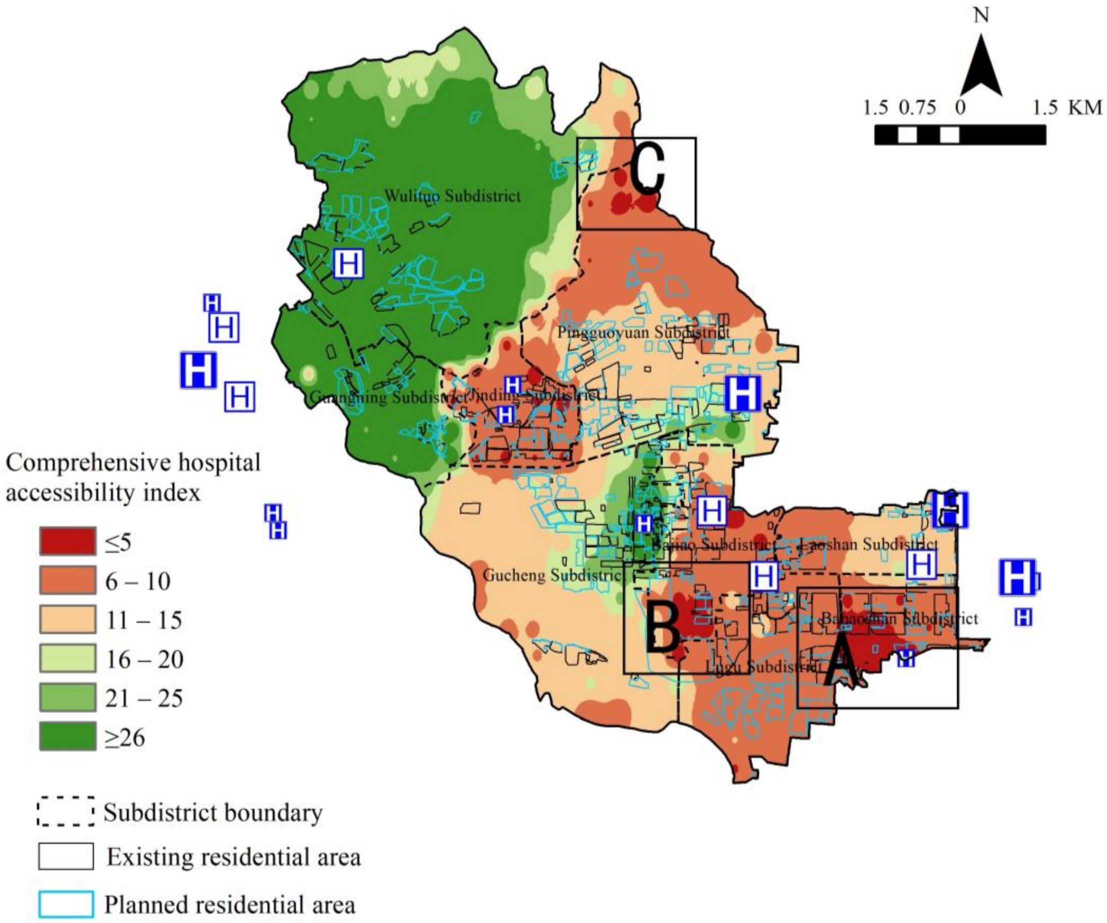

Figure 11. The key areas of medical facility layout optimization in Shijingshan District.

4.3.3. Optimization Strategies

(1) Optimize traffic infrastructure, and strengthen traffic diversion and management. The south of Wulituo Subdistrict and the north of Guangning Subdistrict (Area A in Figure 10), the south of Pingguoyuan Subdistrict (Area B in Figure 10), and the northeast of Gucheng Subdistrict (Area C in Figure 10) are densely distributed areas with a large number of residential areas. In these areas, residential, commercial, educational, medical, and other land use types are mixed, and the phenomenon of mixed traffic and illegal parking is serious. The peak periods of various travel modes (especially commuting to work and school) are superimposed on each other, and the roads in the region are relatively narrow, which aggravates the impact of traffic congestion on comprehensive hospital accessibility. In view of the current situation of the poor quality of transportation infrastructure in the above areas, the main roads in the area should be widened, and the pedestrians and vehicles should be diverted. It is also possible to consider setting the narrower secondary roads in the area as one-way lines according to the specific travel needs of residents, so as to reduce traffic congestion by optimizing the traffic flow. At the same time, the above-mentioned areas should focus on adding parking lots while carrying out urban renewal construction, regulating parking behavior along the road, and dividing fixed parking areas for motor vehicles and non-motor vehicles, so as to reduce traffic congestion caused by illegal parking. In addition, in view of the traffic congestion caused by the superposition

of various travel modes during the peak period in the above areas, traffic diversion and management methods that optimize commuter routes and promote staggered travel should be adopted. For example, staggered commuting between different enterprises and units can be encouraged in areas with dense residential and business districts (Area A, Area B, and Area C in Figure 10). In areas with dense educational facilities (Area A and Area B in Figure 10), it is possible to encourage timed dismissal between different schools and grades. In addition, it is also possible to relieve the traffic pressure during peak hours by clearly dividing the bus and taxi lanes.

(2) Optimize the layout of medical facilities. For areas with poor hospital accessibility due to a lack of medical facilities, additional medical facilities could be appropriately added according to the practical situation. For example, for Babaoshan Subdistrict and Bajiao Subdistrict (Area A and Area B in Figure 11), the construction of medical facilities, especially higher-level hospitals, should be increased according to the construction and population distribution of residential areas; for Pingguoyuan Subdistrict (Area C in Figure 11), the construction of first aid stations or community medical service facilities should be appropriately increased based on the perspective of optimally allocating regional medical resources, rather than the addition of large-scale, high-level hospitals.

(3) Establish a real-time feedback mechanism for traffic data. Make full use of the online map real-time navigation technology and related data to predict the real-time traffic congestion in the area, predict and analyze the time period and area of traffic congestion, and provide timely and relevant feedback data to government departments (such as traffic management departments and medical management departments). The online map platform or government department information release platform will release relevant information to residents opportunely and provide the best travel route for medical treatment based on real-time traffic data, so as to improve the travel efficiency of residents' self-driving medical treatment behavior, thereby reducing the impact of traffic congestion on comprehensive hospital accessibility.

5. Discussion

Based on the improved potential model, combined with multi-source data and Web Mapping API, this study takes Shijingshan District, Beijing, China as an empirical case to assess the hospital accessibility of medical facilities at different levels in different time periods. The specific analysis results show that hospital accessibility in Shijingshan District presents significant spatial and temporal differentiation characteristics: hospital accessibility on weekends is better than that of weekdays, while hospital accessibility in the northwest region is better than the Southeast region. Through further specific analysis, the key optimization areas of the transportation system are Wulituo Subdistrict, Guangning Subdistrict, Pingguoyuan Subdistrict, and Gucheng Subdistrict, and the key areas for optimizing the layout of medical facilities are Bajiao Subdistrict, Babaoshan Subdistrict, and Pingguoyuan Subdistrict.

Hospital accessibility has always been an extremely important research topic in the field of urban planning, which has been consistently and extensively studied by scholars around the world. At the level of the system structure of medical facilities, many countries have adopted and are still promoting the hierarchical diagnosis and treatment system. Medical facilities at different levels have different service capabilities (and scales) and layout requirements, resulting in differences in hospital accessibility. In addition, traffic conditions at different time periods will cause differences in hospital accessibility at different time periods. However, most of the existing studies use the ArcGIS platform to simulate and calculate the travel time and distance for medical treatment in a relatively singular scenario, so as to evaluate the hospital accessibility in a certain area, which fails to fully consider the realistic impact of the different levels of medical facilities and different time periods on hospital accessibility and cannot accurately and effectively assess hospital accessibility. In addition, the simulation results presented under a single scenario are less refined and less relevant to the real situation, and it fails to provide urban planners and policy makers with practical reference information at the spatial layout level of urban medical facilities.

In this study, medical facilities at different levels and traffic conditions at different time periods were integrated into the analysis of hospital accessibility. First, by combining multi-source data and Web Mapping API, the hospital accessibility travel time under real traffic conditions was obtained, and the time thresholds for residents travel to hospitals at different levels were calculated. Then, the improved potential model was used to measure the comprehensive hospital accessibility index of medical facilities at different levels in different time periods. The research method adopted in this study is a beneficial exploration to conduct a more comprehensive and specific hospital accessibility study, so as to propose the analysis result that is more in line with the actual situation and residents' needs. The analysis results of this study show that traffic congestion and the layout of medical facilities are the two most important factors affecting the temporal and spatial differentiation of hospital accessibility. From the analysis in Section 4, it can be seen that traffic congestion has a significant impact on the spatial differentiation of hospital accessibility in different regions (especially in the morning and evening peak periods). As shown in Figure 10, the area where the comprehensive hospital accessibility index decreased significantly under the influence of traffic congestion accounted for nearly 30% of the total area of Shijingshan District. Therefore, optimizing traffic infrastructure and strengthening traffic diversion and management are essential for improving hospital accessibility. At the same time, the unbalanced spatial layout of medical facilities also greatly affects the spatial differences in hospital accessibility. As shown in Figure 11, even in the absence of traffic congestion, nearly 50% of Shijingshan District still has a poor comprehensive hospital accessibility index, and it is necessary to optimize and adjust the spatial layout of medical facilities at different levels in combination with the specific medical needs in the region (spatial distribution of the population) in order to achieve spatial balance and spatial equity in medical accessibility. This research can provide strong support for the optimization of the spatial layout of urban medical facilities and provide practical reference information for urban planners, urban operators, medical managers, and policymakers when formulating public facilities planning and urban medical facilities planning.

This study has several limitations. First, due to the limitations of data acquisition methods, this study analyzes hospital accessibility based on the perspective of residents' self-driving travel mode. In actual medical treatment scenarios, different forms of transportation can be used in the process of medical treatment, including ambulances and public transportation. Analyzing the characteristics of hospital accessibility under different modes of transportation is the direction of further research. Second, although this study attempts to analyze the cross-regional medical treatment situation of residents in Shijingshan District by demarcating buffer zones, this method cannot fully reflect the residents' inter-district medical treatment due to the inability to obtain the specific medical treatment data of each hospital. Therefore, it is impossible to fully analyze the impact of medical facilities in the surrounding area on the hospital accessibility of Shijingshan District. In future research, specific hospital diagnosis and treatment data (such as outpatient case data, etc.) can be combined to enrich the research on cross-regional medical treatment behavior. Third, due to the limitations on computing power and data sources, we assumed that the farthest inter-district travel distance (i.e., the range of the buffer zone) of residents is 2 km, which is a weakness in the research design. In the follow-up research, the search scope and number of medical facilities can be further expanded so as to calculate the hospital accessibility more accurately. In future research, the scope and number of medical facilities can be further expanded in order to more accurately analyze hospital accessibility in the context of cross-regional medical treatment behavior.

6. Conclusions

This research proposes an accessibility measurement method based on Web Mapping API and improved potential model in Shijingshan District, Beijing, and was considered an empirical case. The results showed that there were significant spatial and temporal differences in hospital accessibility in Shijingshan District, and traffic congestion and the medical facility layout were the two most important factors affecting the spatial and temporal pattern of hospital accessibility. Through further analysis of the two influencing factors of traffic congestion and the medical facility layout, the research identified key areas for accessibility optimization and put forward targeted optimization strategies, and provided a scientific basis with which local governments can optimize the spatial structure of transportation and medical facilities. Future works can further expand the research dimension of hospital accessibility assessment by studying accessibility under different modes of transportation modes (such as ambulance and public transportation).

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References

1. World Health Organization (WHO). Available online: https://www.who.int/publications/i/item/9789241548038 (accessed on 4 July 2022).
2. Neutens, T. Accessibility, equity and health care: Review and research directions for transport geographers. *J. Transp. Geogr.* **2015**, *43*, 14–27. [CrossRef]
3. Lee, D.C.; Carr, B.G.; Smith, T.E.; Tran, V.C.; Polsky, D.; Branas, C.C. The impact of hospital closures and hospital and population characteristics on increasing emergency department volume: A geographic analysis. *Popul. Health Manag.* **2015**, *18*, 459–466. [CrossRef] [PubMed]
4. Jia, P.; Xierali, I.M.; Wang, F. Evaluating and re-demarcating the hospital service areas in Florida. *Appl. Geogr.* **2015**, *60*, 248–253. [CrossRef]
5. Goodman, D.C.; Fisher, E.; Stukel, T.A.; Chang, C. The distance to community medical care and the likelihood of hospitalization: Is closer always better? *Am. J. Public Health* **1997**, *87*, 1144–1150. [CrossRef]
6. Wilkin, D. Primary care budget holding in the United Kingdom National Health Service: Learning from a decade of health service reform. *Med. J. Aust.* **2002**, *11*, 539–542. [CrossRef]
7. Goldfield, N.; Gnani, S.; Majeed, A. Profiling performance in primary care in the United States. *BMJ* **2003**, *326*, 744. [CrossRef]
8. Ricarda, M.; Carl, R.B. The Health Care Strengthening Act: The next level of integrated care in Germany. *Health Pol.* **2016**, *120*, 445–451. [CrossRef]
9. Ossi, K.; Aleksi, N.; Tiina, L.; Tiina, H.; Eric, D.; Harri, A. Geographical accessibility to primary health care in Finland—Grid-based multimodal assessment. *Appl. Geogr.* **2021**, *136*, 102583. [CrossRef]
10. Yiling, S.; Junyan, Y.; Michael, K.; Kun, S.; Ying, L.; Cheng, G. Spatial Accessibility Patterns to Public Hospitals in Shanghai: An Improved Gravity Model. *Prof. Geogr.* **2022**, *74*, 265–289. [CrossRef]
11. Paulo, B.; Paulo, G. Health care systems in transition: Brazil: Part I: An outline of Brazil's health care system reforms. *J. Public Health* **1996**, *18*, 289–295. [CrossRef]

12. Shroff, Z.C.; Marten, R.; Ghaffar, A.; Kabir, S.; Hendrik, B.; Manoj, J.; Soumya, S. On the path to Universal Health Coverage: Aligning ongoing health systems reforms in India. *BMJ Glob. Health* **2020**, *5*, 3801. [CrossRef] [PubMed]
13. Lechowski, Ł.; Jasion, A. Spatial Accessibility of Primary Health Care in Rural Areas in Poland. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9282. [CrossRef] [PubMed]
14. Shaoyao, Z.; Xueqian, S.; Jie, Z. An equity and efficiency integrated grid-to-level 2SFCA approach: Spatial accessibility of multilevel healthcare. *Int. J. Equity Health* **2021**, *20*, 229. [CrossRef]
15. National Bureau of Statistics. Available online: http://www.stats.gov.cn/tjsj/zxfb/202002/t20200228_1728913.html (accessed on 4 July 2022).
16. Hansen, W.G. How accessibility shapes land-use. *J. Am. Inst. Plan.* **1959**, *25*, 73–76. [CrossRef]
17. Khan, A.A. An integrated approach to measuring potential spatial access to health care services. *Socio-Econ. Plan. Sci.* **1992**, *26*, 275–287. [CrossRef]
18. Zheng, S.; Wen, C.; Qian, C.; Lei, Z. Measurement of Spatial Accessibility to Health Care Facilities and Defining Health Professional Shortage Areas Based on Improved Potential Model: A Case Study of Rudong County in Jiangsu Province. *Sci. Geogr. Sin.* **2010**, *30*, 213–219. [CrossRef]
19. Penchansky, R.; Thomas, J.W. The Concept of Access: Definition and Relationship to Consumer Satisfaction. *Med. Care* **1981**, *19*, 127–140. [CrossRef] [PubMed]
20. Tobias, M.; Silva, N.; Rodrigues, D. A107 perception of health and accessibility in Amazonia: An approach with GIS mapping to making decision on hospital location. *J. Trans. Health* **2015**, *2*, 60–61. [CrossRef]
21. Dewulf, B.; Neutens, T.; de Weerdt, Y.; van de Weghe, N. Accessibility to primary health care in Belgium: An evaluation of policies awarding financial assistance in shortage areas. *BMC Fam. Pract.* **2013**, *14*, 122. [CrossRef]
22. Sreemongkol, K.; Lohatepanont, M.; Cheewinsiriwat, P.; Bunlikitkul, T.O.; Supasaovapak, J. GIS Mapping Evaluation of Stroke Service Areas in Bangkok Using Emergency Medical Services. *ISPRS Int. J. Geo-Inf.* **2021**, *10*, 651. [CrossRef]
23. Lovett, A.; Sunnenberg, G.; Haynes, R. Using GIS to assess accessibility to primary health care services. *Public Health Pract.* **2004**, *2*, 187–204.
24. Fan, P.; Xu, L.; Yue, W.; Chen, J. Accessibility of public urban green space in an urban periphery: The case of Shanghai. *Landsc. Urban Plan.* **2016**, *165*, 177–192. [CrossRef]
25. Guagliardo, M.F. Spatial accessibility of primary care: Concepts, methods and challenges. *Int. J. Health Geogr.* **2004**, *3*, 3. [CrossRef] [PubMed]
26. Yang, N.; Chen, S.; Hu, W.L.; Wu, Z.; Chao, Y. Spatial distribution balance analysis of hospitals in Wuhan. *Int. J. Environ. Res. Public Health* **2016**, *13*, 971. [CrossRef]
27. Ngamini Ngui, A.; Vanasse, A. Assessing spatial accessibility to mental health facilities in an urban environment. *Spat. Spat. Epidemiol.* **2012**, *3*, 195–203. [CrossRef]
28. Wang, F. Measurement, Optimization, and Impact of Health Care Accessibility: A Methodological Review. *Ann. Am. Assoc. Geogr.* **2012**, *102*, 1104–1112. [CrossRef]
29. Yiannakoulias, N.; Bland, W.; Svenson, L.W. Estimating the effect of turn penalties and traffic congestion on measuring spatial accessibility to primary health care. *Appl. Geogr.* **2013**, *39*, 172–182. [CrossRef]
30. Andersen, R. A behavioral model of families' use of health services. *J. Hum. Resour.* **1968**, *7*, 125.
31. Luo, W.; Wang, F. Measures of spatial accessibility to health care in a GIS environment: Synthesis and a case study in the Chicago region. *Environ. Plann. Plann. Des.* **2003**, *30*, 865–884. [CrossRef]
32. Wang, F.H.; Luo, W. Assessing spatial and non-spatial factors for healthcare access: Towards an integrated approach to defining health professional shortage areas. *Health Place* **2005**, *11*, 131–146. [CrossRef]
33. Xing, L.; Liu, Y.; Wang, B.; Wang, Y.; Liu, H. An environmental justice study on spatial access to parks for youth by using an improved 2SFCA method in Wuhan, China. *Cities* **2020**, *96*, 102405. [CrossRef]
34. Wan, N.; Zou, B.; Sternberg, T. A three-step floating catchment area method for analyzing spatial access to health services. *Int. J. Geogr. Inf. Sci.* **2012**, *26*, 1073–1089. [CrossRef]
35. Zhang, F.; Li, D.; Sherry, A.; Zhang, J. Assessing spatial disparities of accessibility to community-based service resources for Chinese older adults based on travel behavior: A city-wide study of Nanjing, China. *Habitat Int.* **2019**, *88*, 101984. [CrossRef]
36. Ye, C.; Hu, L.; Li, M. Urban green space accessibility changes in a high-density city: A case study of Macau from 2010 to 2015. *J. Transp. Geogr.* **2018**, *66*, 106–115. [CrossRef]
37. Wang, H.; Wei, X.; Ao, W. Assessing Park Accessibility Based on a Dynamic Huff Two-Step Floating Catchment Area Method and Map Service API. *ISPRS Int. J. Geo-Inf.* **2022**, *11*, 394. [CrossRef]
38. Luo, W.; Qi, Y. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. *Health Place* **2009**, *15*, 1100–1107. [CrossRef]
39. Xiao, Y.; Chen, X.; Li, Q.; Jia, P.; Li, L.; Chen, Z. Towards healthy China 2030: Modeling health care accessibility with patient referral. *Soc. Sci. Med.* **2021**, *276*, 113834. [CrossRef]
40. Liu, Z.; Yang, H.; Xiong, W.; Chen, G. Spatial accessibility of medical services at county level based on optimized two-step floating catchment area method. *Sci. Geogr. Sin.* **2017**, *5*, 91–100. [CrossRef]
41. Cheng, G.; Zeng, X.; Duan, L.; Lu, X.; Sun, H.; Jiang, T.; Li, Y. Spatial difference analysis for accessibility to high level hospitals based on travel time in Shenzhen, China. *Habitat Int.* **2016**, *53*, 485–494. [CrossRef]

42. Cheng, M.; Lian, Y. Spatial accessibility of urban medical facilities based on improved potential model: A case study of Yangpu District in Shanghai. *Prog. Geogr.* **2018**, *37*, 266–275. [CrossRef]
43. Schuurman, N.; Bérubé, M.; Crooks, V.A. Measuring potential spatial access to primary health care physicians using a modified gravity model. *Can. Geogr.* **2010**, *54*, 29–45. [CrossRef]
44. Cheng, M.; Tao, L.; Lian, Y.; Huang, W. Measuring Spatial Accessibility of Urban Medical Facilities: A Case Study in Changning District of Shanghai in China. *Int. J. Environ. Res. Public Health* **2021**, *18*, 9598. [CrossRef] [PubMed]
45. Ding, S.; Chen, B. Rationality Assessment of the Spatial Distributions of Urban Medical Facility. *J. Geo-Inf. Sci.* **2017**, *19*, 185–196. [CrossRef]
46. Zheng, Z.; Zhang, L.; Qin, Y.; Xie, Z.; Rong, P.; Li, Y. Analysis of medical accessibility in Kaifeng based on Internet map service. *Res. Sci.* **2018**, *11*, 2307–2316. [CrossRef]
47. Zhou, Y.; Li, Y.; Huang, Y.; Geng, E. Classification and activity characteristics analysis of urban population based on social media data. *J. Geoinf. Sci.* **2017**, *19*, 1238–1244. [CrossRef]
48. Niu, Q.; Wang, Y.; Xia, Y.; Wu, H.; Tang, X. Detailed Assessment of the Spatial Distribution of Urban Parks According to Day and Travel Mode Based on Web Mapping API: A Case Study of Main Parks in Wuhan. *Int. J. Environ. Res. Public Health* **2018**, *15*, 1725. [CrossRef] [PubMed]
49. Choi, W.; Min, S.; Jang, I.; Chang, Y. The Comparative Research On 2D Web Mapping Open API for Designing Geo-Spatial Open Platform. *J. Kor. Spat. Inf. Soc.* **2014**, *22*, 87–98. [CrossRef]
50. Zhou, X.; Kim, J. Social disparities in tree canopy and park accessibility: A case study of six cities in Illinois using GIS and remote sensing. *Urban For. Urban Green.* **2013**, *12*, 88–97. [CrossRef]
51. Xia, N.; Cheng, L.; Chen, S.; Wei, X.; Zong, W.; Li, M. Accessibility based on Gravity-Radiation model and Google Maps API: A case study in Australia. *J. Transp. Geogr.* **2018**, *72*, 178–190. [CrossRef]
52. Zheng, Z.; Shen, W.; Li, Y.; Qin, Y.; Wang, L. Spatial equity of park green space using KD2SFCA and web map API: A case study of Zhengzhou, China. *Appl. Geogr.* **2020**, *123*, 102310. [CrossRef]
53. Xu, M.; Xin, J.; Su, S.; Weng, M.; Cai, Z. Social inequalities of park accessibility in Shenzhen, China: The role of park quality, transport modes, and hierarchical socioeconomic characteristics. *J. Transp. Geogr.* **2017**, *62*, 38–50. [CrossRef]
54. Rong, P.; Zheng, Z.; Kwan, M.; Qin, Y. Evaluation of the spatial equity of medical facilities based on improved potential model and map service API: A case study in Zhengzhou, China. *Appl. Geogr.* **2020**, *119*, 102192. [CrossRef]
55. Zheng, Z.; Xia, H.; Ambinakudige, S.; Qin, Y.; Li, Y.; Xie, Z.; Zhang, L.; Gu, H. Spatial Accessibility to Hospitals Based on Web Mapping API: An Empirical Study in Kaifeng, China. *Sustainability* **2019**, *11*, 1160. [CrossRef]
56. Zheng, S.; Wen, C. Measuring Spatial Accessibility to Health Care Facilities Based on Potential Model. *Progr. Geogr.* **2009**, *28*, 848–854.
57. Beijing Transport Institute. Available online: https://www.bjtrc.org.cn/List/index/cid/7.html (accessed on 4 July 2022).
58. Joseph, A.E.; Bantock, P.R. Measuring potential physical accessibility to general practitioners in rural areas: A method and case study. *Soc. Sci. Med.* **1982**, *16*, 85–90. [CrossRef]
59. National Health Commission of the People's Republic of China. Available online: http://www.nhc.gov.cn/yzygj/s7657/202012/c46f97f475da4d60be21641559417aaf.shtml (accessed on 4 July 2022).
60. Wang, X.; Yang, H.; Duan, Z.; Pan, J. Spatial accessibility of primary health care in China: A case study in Sichuan Province. *Soc. Sci. Med.* **2018**, *209*, 14–24. [CrossRef]
61. Zeng, W.; Xiang, L.; Li, H.; Zhang, X.; Zhang, H. Spatial pattern and formation mechanism of accessibility of medical service facilities in Nanjing, China. *Econo. Geogr.* **2017**, *37*, 136–143. [CrossRef]
62. Shijingshan District People's Government of Beijing Municipality. Available online: http://www.bjsjs.gov.cn/sjsview/qqgk/ (accessed on 4 July 2022).
63. The Seventh National Population Census Bulletin of Beijing Shijingshan District. Available online: http://www.bjsjs.gov.cn/ywdt/sjsdt/20210611/15215453.shtml (accessed on 4 July 2022).
64. Beijing Municipal Commission of Transportation. Available online: http://service.jtw.beijing.gov.cn/creditTransport/ (accessed on 4 July 2022).
65. Beijing Municipal Government Affairs Data Resource Network. Available online: https://data.beijing.gov.cn/zyml/azt/index.htm (accessed on 4 July 2022).
66. Beijing City Lab. Available online: https://www.beijingcitylab.com/ (accessed on 4 July 2022).
67. Reggiani, A.; Bucci, P.; Russo, G. Accessibility and impedance forms: Empirical applications to the German commuting network. *Int. Reg. Sci. Rev.* **2011**, *34*, 230–252. [CrossRef]
68. Peeters, D.; Thomas, I. Distance predicting functions and applied location-allocation models. *J. Geogr. Syst.* **2000**, *2*, 167–184. [CrossRef]
69. Wang, F. Modeling Commuting Patterns in Chicago in a GIS Environment: A Job Accessibility Perspective. *Prof. Geogr.* **2000**, *52*, 120–133. [CrossRef]
70. Tao, H.; Chen, X.; Li, X. Research on Spatial Accessibility of Public Medical and Health Services: Taking Haizhu District of Guangzhou City as an Example. *Geomapp. Spat. Inf. Technol.* **2007**, *30*, 1–5.
71. Wu, J.; Kong, Y.; Li, B. Spatial accessibility analysis of rural medical facilities based on GIS: A Case Study of Taking Lankao County, Henan Province as an example. *Hum. Geogr.* **2008**, *5*, 37–42. [CrossRef]

72. Wang, F.; Zhang, C. Application of GIS and Gravitational Polygon Methods in Public Facility Service Domain Research: A Case Study of Shanghai Pudong New Area General Hospital. *Econ. Geogr.* **2005**, *25*, 800–809. [CrossRef]
73. Wang, X.; Pan, J. Assessing the Disparity in Spatial Access to Hospital Care in Ethnic Minority Region in Sichuan Province, China. *BMC Health Serv. Res.* **2016**, *16*, 399. [CrossRef]
74. Chen, B.Y.; Cheng, X.P.; Kwan, M.P.; Schwanen, T. Evaluating Spatial Accessibility to Healthcare Services Under Travel Time Uncertainty: A Reliability-based Floating Catchment Area Approach. *J. Transp. Geogr.* **2020**, *87*, 102794. [CrossRef]