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Article

An Improved Accessibility-Based Model to Evaluate Educational Equity: A Case Study in the City of Wuhan

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Abstract: Limited studies focus on educational equity from the spatial accessibility perspective. This study combines survey data and big data and proposes a multi-mode Huff two-step floating catchment area (MMH2SFCA) method to calculate accessibility while considering multiple travel modes and school attractiveness. This method can also calculate education quality by extending the accessibility in each community. Results show that our proposed method can reliably identify the accessibility differences of schools across communities. The case study indicates an inequitable distribution of educational accessibility and quality. The communities with high accessibility are concentrated in the urban center and exurban zones surrounding schools, whereas high-quality areas are mainly concentrated in the urban center. Correlation analysis suggests that the educational quality of communities with high accessibility is not always high. The findings of this study can provide improvement for accessibility measurements and help explore a new research perspective for educational equity research.

Keywords: accessibility; educational equity; spatial equity; 2SFCA; multiple travel modes; Huff model

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1. Introduction

Education is a basic human right that is important for peace, tolerance, human fulfilment and sustainable development [1]. Educational equity ensures the effectiveness of the education system and is an important part of social equity [2]. Educational equity includes not only equal access to education, but also equal quality of education through the balanced distribution of educational resources, and within such a system, students have the same opportunity to achieve a high level of achievement [3]. Research on educational equity has been widely conducted by scholars [4–8], mainly including gender [6], age [7], race [4], disability [9] and socioeconomic status [8], and several others. Meanwhile, policy, finance, and education quality have also been shown to affect educational equity [5,10,11]. In addition, "education capitalization" [12] is also a research hotspot. By studying the relationship between housing prices and educational facilities, these studies reveal the impact of income and housing prices on educational equity [12–15]. However, these studies have not investigated the influence of spatial factors. Social equity is often combined with spatial accessibility [16,17]. For instance, low accessibility is a sign of social exclusion [18]. Thus, by developing further understanding of this phenomenon, the lens of accessibility also informs our approach to a more equal society [19]. Therefore, exploring the accessibility of student groups to schools is helpful in evaluating educational equity and exploring social equity.

Some related studies have shown that spatial equity from the perspective of space is conducive to the realization of social equity [20–22]. Spatial equity is a concept evolved from social equity [23]. There are various definitions of spatial equity. Tsou et al. [19] point out that spatial equity refers to the relatively uniform distribution of services relative to residents' needs, preferences and service standards. When discussing the distribution of urban facilities, the concept of spatial equity can be divided into "horizontal spatial equity" and "vertical spatial equity" [24,25]. Horizontal spatial equity holds that residents should be guaranteed to enjoy facilities and services equitably through consistent distribution [19,25,26]. Vertical spatial equity focuses on the needs of different groups and holds that vulnerable groups should be guaranteed to enjoy resources and services equitably through inclined allocation of resources [24–27]. Spatial equity concerns differences in service levels between regional public facilities [28]. Analyzing the spatial equity of facilities helps urban planners assess the consequences of current strategies for the more equitable allocation of urban facilities [24,29]. Many statistical methods are used for spatial equity evaluation, such as analysis of variance (ANOVA) [30], Spearman correlation [24], ordinary least square linear regression and spatial regressions [31], Theil index [2], Lorenz curve and Gini coefficient [32,33], and bivariate local Moran's I [34]. However, most of these methods depend on spatial accessibility results.

Accessibility has been widely recognized by researchers as an important standard to measure the fairness of resource or service space [19,24,35–37]. Hansen [38] defined accessibility as "the potential of opportunities for interaction". It can indicate the opportunity for people in a certain place to participate in a specific activity [24]. Researchers divide accessibility into spatial accessibility and non-spatial accessibility [24,39]. In this study, we focus on spatial accessibility. Many scholars have studied the accessibility of public facilities, analyzed the spatial equity of corresponding resources/services, and explored social equity [18,35,36,40]. Many models and methods have been used to measure the spatial accessibility of facilities, such as buffer analysis [41], kernel density estimation [42], the Voronoi diagram method [43], the cumulative opportunity measure [44], the gravity model [45], etc. In addition, the increasingly popular 2SFCA algorithm and its extension consider the supply–demand relationship between facilities and people and have been widely used to evaluate the potential spatial accessibility of various public facilities [46–49].

As a common method to measure accessibility, 2SFCA has been proposed to overcome the defect of only considering the cost (distance, time, etc.) between supply facilities and demand places. Since Luo and Wang [46] first proposed the introduction of the supply–demand relationship in the calculation of accessibility, many scholars have improved the method. First, considering the attenuation distance, the cost (usually distance or travel time) between the supply facilities and the demand places is introduced into the method as impedance, such as enhanced 2SFCA (E2SFCA) [47], gravity 2SFCA (G2SFCA) [50], kernel density 2SFCA (KD2SFCA) [51], and Gaussian 2SFCA (Ga2SFCA) [21]. Second, considering the search radius, the original fixed search radius is modified according to the actual situation, such as variable 2SFCA (V2SFCA) [52] and dynamic 2SFCA (D2SFCA) [53]. Third, the improvement of 2SFCA can also consider the introduction of competitive factors, for example, the three-step floating catchment area (3SFCA) method [54] and the Huff 2SFCA (H2SFCA) method [49]. Finally, considering multiple modes of travel is also an expansion direction, such as multi-mode 2SFCA (MM2SFCA) [48], commuter-based 2SFCA (CB2SFCA) [55], multi-mode 3SFCA (MM3SFCA) [56], and MTM-RTMC G2SFCA [57].

It is an effective way to improve the understanding of educational equity by improving the measurement of accessibility. Considering educational equity from the perspective of space, some studies have studied educational inequality at the national or provincial level [2,58]. At the city level, although some studies involve the spatial equity of educational facilities, they mainly focus on the equity of transportation [59,60]. In other studies, schools are regarded as common public facilities, and with other facilities to study the spatial equity of urban public facilities [18,35,36,40]. Although these studies discussed spatial accessibility, they ignored the differences between schools and other public facilities.

At present, some scholars have studied the accessibility of educational facilities to evaluate educational equity [61–65]. Some studies have used simple spatial distance [63,66] or the original 2SFCA method to study the spatial accessibility of students to school [61], but the simple modeling ignores the students' choice of school and the complex behavior of school travel. At the same time, education equity should consider not only the entrance opportunities of students, but also the quality of education they receive. Spatial accessibility can reflect students' entrance opportunities, but it cannot measure the quality of education received by students. High-quality schools are more attractive to students given that high-quality education resources are scarce and unevenly distributed [67–69]. While students tend to choose a high school based on the attractiveness of the school, some related studies have ignored the impact of education quality on accessibility [61]. In addition, transport has been identified to play a crucial role in accessing education [34], but some studies only considered the impact of a single travel mode on accessibility [65]. This is different from the actual situation, especially in China, where students often go to school by walking, biking, public transport, or car.

Although multiple modes of travel have been incorporated into 2SFCA [34,48,70], they mostly applied the same search threshold for different modes of travel, ignoring the attraction of facilities. Moreover, they also estimated travel time based on an assumed speed through the road network, which may interfere with the final result. On the other hand, the attractiveness generated by the quality of schools cannot be ignored for the preference of high-quality schools by students and their parents [12,14,71,72]. Although Luo [49] introduced the Huff model to 2SFCA to calculate accessibility, it is impractical to evaluate the attractiveness of a school using only its capacity and one traffic mode.

As mentioned above, although previous studies have researched the spatial equity of education, few studies focused on the reliability evaluation measurement of spatial accessibility. Existing accessibility measurements either oversimplify the behavior of one student on the way to school (e.g., directly using spatial distance as an accessibility index) [63] or ignore the special needs of education that are different from other urban public facilities [36]. Meantime, educational equity includes both the access to schools and the education quality the students receive. Spatial accessibility can be regarded as a factor reflecting opportunities for students to receive education [38,72,73]. However, it cannot evaluate the educational quality. Therefore, it is necessary to attempt to develop a comprehensive approach that can evaluate both the educational accessibility and quality.

Based on the above deficiencies, this study attempts to solve the following issues: (1) How to measure the accessibility and quality of educational resources reliably. (2) Whether and how the accessibility and quality distribution of educational resources are equitable in the MDZ of Wuhan according to our method. This study proposed a method of multi-mode Huff two-step floating catchment area (MMH2SFCA) to calculate school accessibility, which considered multiple travel modes and school attractiveness. Additionally, we also measured community education quality by extending the accessibility of each community to comprehensively evaluate educational equity. We then took Wuhan's metropolitan development zone (MDZ) as the case study area and used the proposed method to measure the accessibility of high schools by combining traditional survey data and big data. In general, our study has the following contributions: first, the 2SFCA method is improved and extended by considering multiple travel modes and school attractiveness, and our method combines the advantages of the existing 2SFCA method and improves the unreasonable assumption of using a single mode of travel and treating all school facilities equally; second, through the calculation of accessibility and quality, it provides a multi-perspective evaluation method for educational equity. Third, this paper investigates potential policy implications as a result of our findings to serve not only Wuhan, but also other cities in the world through the evaluation of educational equity based on the measurement of educational accessibility and quality.

The rest of the paper is organized into sections. The second section describes the improved method in detail. The fourth section introduces the study area and data sources. The third section presents the measurement results of the accessibility of schools in Wuhan's MDZ using our improved method and the existing 2SFCA method. This section also discusses some findings from the perspective of accessibility and quality. In the fifth section, we discuss the advantages of the method, the policy implications of this research and the limitations of the study. The final section consists of the key conclusions of this study.

2. Methods

The proposed MMH2SFCA method considers the attractiveness of schools along with students' multiple modes of travel. Specifically, to measure school attractiveness, the quality of the school is calculated according to the identified indicators. After dividing the students into subgroups according to multiple travel modes, the selection probability of students to schools is determined by both the attractiveness and modes of travel. Then, the accessibility of each community is obtained by accumulating the supply–demand ratio of schools corresponding to different travel modes. The quality of the corresponding school is weighted to obtain the education quality of the community (see Figure 1). In our method, the introduction of school attractiveness improves the simple assumption that Luo [49] only uses capacity to represent the impact of facilities on residents. At the same time, the introduction of school attraction is also an improvement on the MM2SFCA method [48], which adopts multiple travel modes but ignores the differences of facilities. Our method using multiple travel modes is more reasonable than the single travel mode in the H2SFCA method [49].

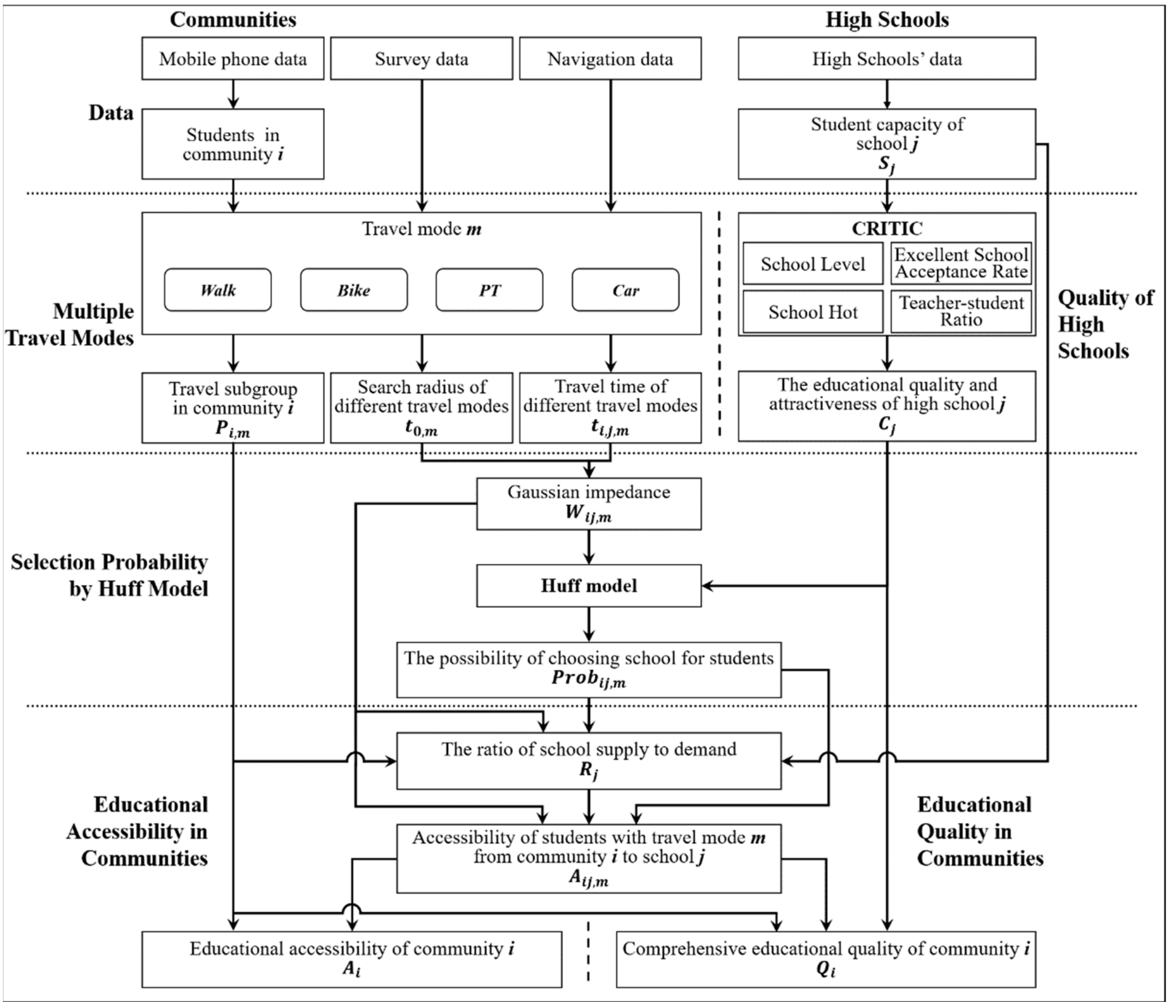

Figure 1. The proposed method to calculate educational accessibility and quality.

2.1. Quality of High Schools

This study measures the attractiveness of schools based on their educational quality because students and parents are generally attracted by schools with higher education quality. Specifically, the calculation of school education quality follows certain aspects. First, the education quality of government-selected model schools is higher than that of ordinary schools [74]. Second, the ratio of teachers to students also reflects the quality of education [75]. In addition, the proportion of graduates who are admitted to excellent universities, and therefore have better career prospects, is also considered [73]. The number of visits in Baidu Baike (similar to Wikipedia) is also taken as an indicator to reflect the popularity of a school. These education quality indicators are summarized in Table 1.

Table 1. Calculation indicators of school education quality.

Indicator Name	Meaning of Indicators
School Level	The model schools selected by the government can be divided into three categories: provincial model schools, municipal model schools, and others.
Excellent School Acceptance Rate	The proportion of graduates who continue to study and are admitted by excellent schools.
School Hot	The social attention of schools, which is reflected by the number of visits in Baidu Baike.
Teacher–Student Ratio	The ratio of teachers to students in schools.

Following this, a data-driven method called CRITIC is used to weigh these indicators by comparing the intensity and conflict [76,77]. The relative weight of the u-th indicator is given by Equation (1):

$$w_u = \frac{I_u}{\sum_{v=1}^{4} I_v}, \tag{1}$$

where

$$I_u = \sigma_u \times \sum_{v=1}^{4} (1 - r_{uv}), \tag{2}$$

In the equation above, σ_u is the standard deviation of normalized indicator u, and r_{uv} is the Spearman correlation coefficient between normalized indicator u and normalized indicator v. The quality of each school C_j is the weighted average of the normalized indicators (Equation (3)), which is between 0 and 1. A higher C_j means higher quality.

$$C_j = \sum_{u=1}^{4} (q_{j,u} \times w_u), \tag{3}$$

where $q_{j,u}$ is the value of the u-th indicator of the j-th school.

2.2. Multiple Travel Modes

In previous studies, researchers often used private cars as the travel mode of people in developed countries [21,49]. However, the application of this simplified scheme in countries or regions with a low motorization rate may overestimate the commuting capacity of residents. For most cities in developing countries, students often go to school by walking, biking, public transport (PT), or private car. Between the same start and destination, the travel duration may vary due to different choice of transportation. In this study, students in the community are divided into four subgroups according to proportion, and each subgroup chooses the corresponding travel mode. Therefore, students in each subgroup have different travel times and search radii. Equation (4) represents the set of travel modes used by students to go to schools.

$$M = \{Walk, Bike, PT, Car\}, \tag{4}$$

2.3. Selection Probability by the Huff Model

The original 2SFCA method and the distance attenuation improved method ignore the competition among facilities, which may lead to some inaccuracies. Although the competition effect is considered in the 3SFCA method, it only takes the distance factor as the factor of people's choice and ignores the influence of the facility itself [54]. In reality, people are also influenced by the characteristics of the facilities. The Huff model can be used to calculate the probability of people's choice of facility [78]. The core of the Huff model is that people have different selection probabilities for different facilities. In the current study, we extended the selection probability in the original H2SFCA to accommodate multiple travel modes. As mentioned above, we regard the quality of the school (C_j) as the attractiveness of the school. The possibility $Prob_{ij,m}$ of choosing school j for students in community i under travel mode m is a function of the attractiveness C_j of the school, and the distance impedance coefficient $W_{ij,m}$ of the travel mode (Equation (5)). In this study, we use the following Gaussian distance impedance function Equation (6), according to Dai [21]. Other available models could also be found in a past study [79].

$$Prob_{ij,m} = \frac{C_j W_{ij,m}}{\sum_{s \in \{t_{i,s,m} \le t_{0,m}\}} C_s W_{is,m}}, \tag{5}$$

$$W_{ij,m} = \begin{cases} \frac{e^{-(1/2) \times (t_{i,j,m}/t_{0,m})^2} - e^{-(1/2)}}{1 - e^{-(1/2)}} & , if\ t_{i,j,m} \le t_{0,m} \\ 0 & , if\ t_{i,j,m} > t_{0,m} \end{cases}, \tag{6}$$

In Equations (5) and (6), $t_{i,s,m}$ is the travel time from community i to school s with travel mode m, and $t_{0,m}$ is the search radius of travel mode m. In addition, $t_{i,j,m}$ and $t_{0,m}$ have the same meaning as described above.

Before we proceed to the definitions of these factors, we illustrate Equation (5) with an example in Figure 2. Students in community i can travel to three schools A, B, and C with varying degrees of attractiveness (0.8, 0.5, 0.3) using different travel modes. For example, the impedances for walking to A, B, and C are 0.3, 0.7, and 0.5, respectively. Then, the probability that a student from community i walks to school A is $(0.8 \times 0.3)/(0.8 \times 0.3 + 0.5 \times 0.7 + 0.3 \times 0.5) \approx 0.324$.

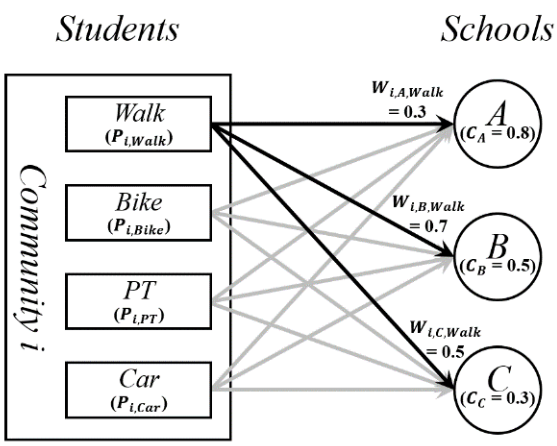

Figure 2. The probabilities of students' choice of different schools in the communities under multiple travel modes.

2.4. Educational Accessibility in Communities

Analogous to 2SFCA, we adjusted the ratio of school supply to demand R_j as Equation (7) to support multiple travel modes:

$$R_j = \frac{S_j}{\sum_{m\epsilon M}\sum_{k\in\{t_{k,j,m}\le t_{0,m}\}}\left(Prob_{kj,m} \times P_{k,m} \times W_{kj,m}\right)}, \quad (7)$$

where S_j is the supply of school j, which, in this study, refers to the number of school students; $Prob_{kj,m}$ is the possibility of choosing school j for people in community k under travel mode m; $P_{k,m}$ is the number of people using mode m in community k; and $W_{kj,m}$ is the distance impedance coefficient from community k to school j by means of travel mode m. In addition, $t_{k,j,m}$ and $t_{0,m}$ have the same meaning as described above.

After that, the accessibility from community i to school j using travel mode m can be recorded as follows:

$$A_{ij,m} = Prob_{ij,m} \times W_{ij,m} \times R_j, \quad (8)$$

where $Prob_{ij,m}$ is the possibility of choosing school j for students in community i under travel mode m, $W_{ij,m}$ is the distance impedance coefficient from community i to school j by means of travel mode m, and R_j is the supply–demand ratio of school j.

Next, the supply–demand ratio of reachable schools from community i by travel mode m is derived by summing $A_{ij,m}$ (Equation (10)). Thus, the overall spatial accessibility for community i is the weighted average of accessibility for each mode, with weights being the number of students using mode m in this community $P_{i,m}$ (Equation (9)).

$$A_i = \frac{\sum_{m\epsilon M}(A_{i,m} \times P_{i,m})}{\sum_{m\epsilon M} P_{i,m}}, \quad (9)$$

$$A_{i,m} = \sum\nolimits_{j\in\{t_{i,j,m}\le t_{0,m}\}} A_{ij,m}, \quad (10)$$

In Equations (9) and (10), $t_{i,j,m}$ and $t_{0,m}$ have the same meaning as described above.

2.5. Educational Quality in Communities

The space accessibility A_i measures the opportunities for students to enter school. However, having such opportunities does not necessarily mean that they can receive high-quality education. In previous studies of 2SFCA, some researchers adjusted the facility capacity by multiplying the adjustment factor so that the result can better reflect the quality of service [80]. In the current study, we present a new approach to calculate the quality of education received by students in the community. The value of $A_{ij,m}$ obtained by Equation (8) is essentially a supply–demand ratio of school j adjusted by selection probability and distance attenuation. The higher the value is, the more educational resources the students in community i will receive from school j when they use the travel mode m. Therefore, the students are more influenced by the educational quality of school j. We calculate the average of the quality of school education (C_j) weighted by corresponding $A_{ij,m}$ values to derive the average education quality ($Q_{i,m}$) of students who use travel mode m in community i (Equation (12)). Then, the quality of education received by the students in community i is the mean value of $Q_{i,m}$ weighted by the number of students in different travel modes (Equation (11)).

$$Q_i = \frac{\sum_{m\epsilon M}(Q_{i,m} \times P_{i,m})}{\sum_{m\epsilon M} P_{i,m}}, \quad (11)$$

$$Q_{i,m} = \frac{\sum_{j\in\{t_{i,j,m}\le t_{0,m}\}}\left(A_{ij,m} \times C_j\right)}{\sum_{j\in\{t_{i,j,m}\le t_{0,m}\}}\left(A_{ij,m}\right)}, \quad (12)$$

In Equations (11) and (12), $t_{i,j,m}$ and $t_{0,m}$ have the same meaning as described above.

3. Case Study: Access to High Schools for Students in Wuhan

3.1. Study Area

Wuhan, the capital of Hubei Province, is located in the east of Jianghan Plain, at the intersection of the Yangtze River and the Hanjiang River. It is a mega city and a strategic transportation hub in Central China. As a new first-tier city in China, Wuhan is densely populated, with a multi-layered and three-dimensional traffic structure. There are various commuting modes in the city, including driving, bus, subway, bicycle, etc. [81]. At the same time, Wuhan is a big city of education, including primary schools, junior high schools, high schools, universities, vocational education and other complete education structures. In the process of rapid urban development, the education problem cannot be ignored, and the education gap is growing. Taking Wuhan as an example, it can provide a typical reference for similar cities at home and abroad and help the government to solve the problem of education equity within the city. We selected the metropolitan development zone (MDZ) of Wuhan as the study area of this article. According to the city master plan for the years 2010 to 2020 [82], the MDZ is the main area for urban function agglomeration and urban space expansion. It includes 15 districts with a total land area of 3269 square kilometers made up of 1927 communities. There are about 120,000 high school-age teenagers (age 16–18) according to mobile phone data in the MDZ. Additionally, there are 77 high schools that can accommodate about 98,000 students (grades 10–12) in the MDZ. The distributions of high school students and high schools in the MDZ are shown in Figure 3.

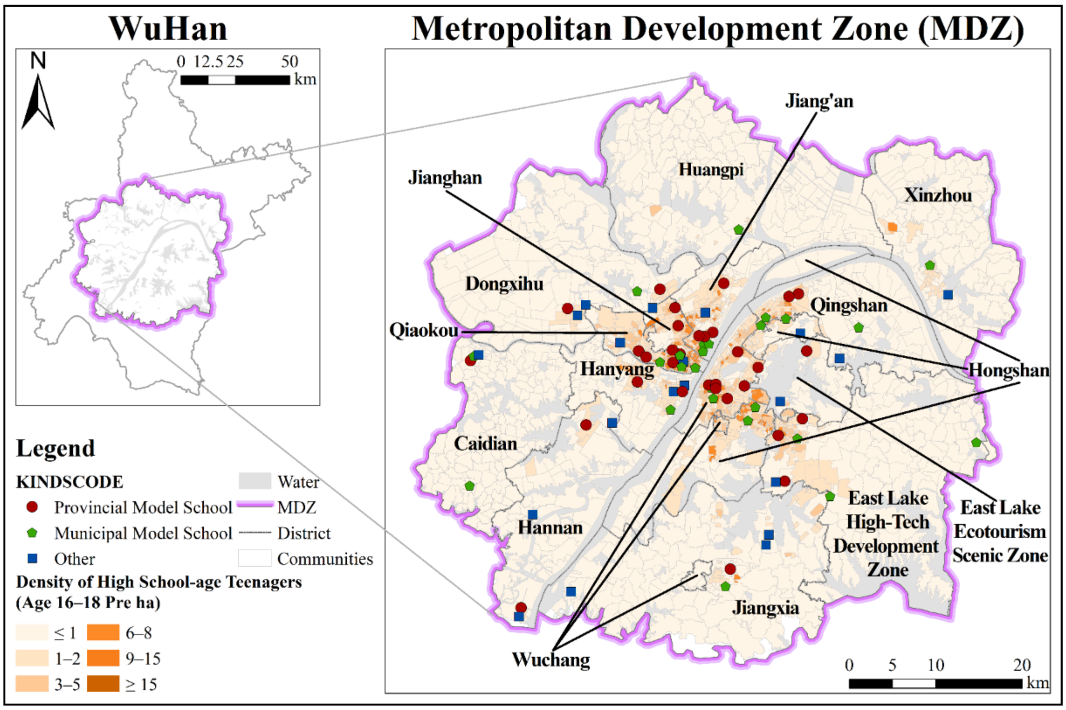

Figure 3. The Metropolitan Development Zone (MDZ) of Wuhan.

3.2. Data

We investigated high school students and high schools in the MDZ of Wuhan in order to evaluate the educational equity. We collected necessary information, including the number of high school-age teenagers in each community, detailed information of each school, the proportions and search radii of different travel modes, and the travel time between each pair of community and school.

We used the distribution of high school-age teenagers as the demand of each community. The distribution of high school-age teenagers comes from China Unicom, which identifies them through mobile phone signaling. Information about high schools in the

MDZ is available from the Wuhan Education Bureau. The locations of schools were obtained through the reverse geocoding service provided by Baidu Maps. We also gathered attributes of each school from the Internet, including capacity, the number of teachers, school level, rates of graduates admitted by excellent universities, and web search popularity.

3.2.1. Survey on Students' Travel Modes

In order to obtain the proportion of high school students going to school through different travel modes and the maximum tolerable travel time of each travel mode, we designed a questionnaire (see Appendix A), which aimed to investigate the travel modes and commuting times of the respondents in high school. Questionnaires were sent to 15–24-year-old users living in Wuhan on a questionnaire platform (https://wj.qq.com, accessed on 3 July 2021) operated by China's largest instant messaging company, Tencent. Finally, we collected 594 questionnaires, of which 486 were valid. A total of 301 questionnaires came from respondents who attend a high school in Wuhan. The results of the questionnaire are shown in Figure 4, in which the inner ring represents the proportion of different travel modes of high school students. Due to the lack of data, this study assumes an identical composition of multiple travel modes across the communities.

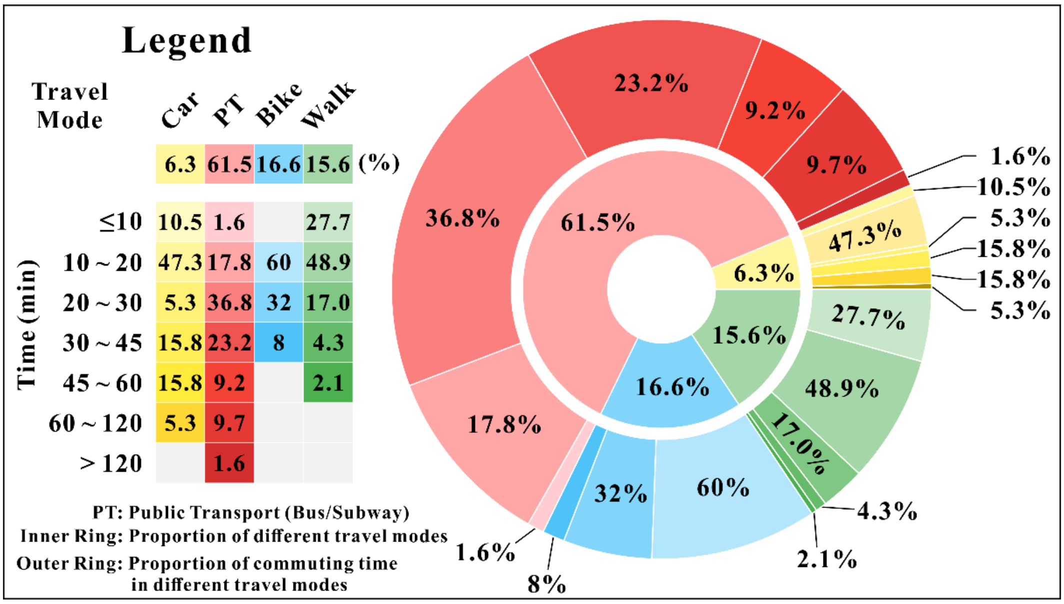

Figure 4. The proportions of travel modes and commuting times of high school students in Wuhan.

The outer ring represents the proportion of commuting time in different travel modes. This helps us define the search radius specific to each travel mode, thus avoiding the problem of failing to consider travel mode differences in previous studies that used a uniform search radius [48,70]. For each mode of travel, we set the search radius to the upper bound of the interval containing the third quartile of commuting time. The proportions and search radii of different travel modes of high school students in the MDZ are shown in Table 2. High school students prefer public transport (PT) to go to school. The proportions of walking and biking are roughly the same, and travel by car is rarely used to go to school. This supports our previous assertion that private cars should not be used as the only travel mode in modeling Chinese high school accessibility.

Table 2. Proportions and search radii of different travel modes used by high school students.

Travel Mode	Walk	Bike	PT	Car
Proportion	0.156	0.166	0.615	0.063
Search radius (min)	20	30	45	45

3.2.2. Travel Times for Different Travel Modes

The travel times from each community to each school were obtained using the route planning service of Baidu Maps. Considering the daily commuting time of high school students, we collected the estimated travel time during the period from 6:00 to 7:30 for four travel modes. Samples of the travel time records are shown in Table 3.

Table 3. Travel time samples.

Community Index	High School Index	Travel Time (min)			
		Walk	Bike	PT	Car
1	1	493	188	116	44
1	2	308	118	78	32
...	...	...	...	...	...

4. Results

We first compared the educational accessibility obtained by the MMH2SFCA method with the existing methods of H2SFCA and MM2SFCA to verify the effectiveness of the improved method. Following this, we compared the educational accessibility and quality of the communities obtained by MMH2SFCA and analyzed the educational equity in the MDZ of Wuhan. In order to exclude the influence of distance impedance models, we used a Gaussian model as in Equation (6) in the H2SFCA and MM2SFCA methods. Hereafter, H2SFCA-Walk, H2SFCA-Bike, H2SFCA-PT, and H2SFCA-Car are used to refer to the corresponding travel modes in the H2SFCA method.

4.1. Comparative Analysis

4.1.1. Accessibility Comparison

Figure 5 shows the results of community-level education accessibility measured by the proposed MMH2SFCA method. To facilitate comparisons of the MMH2SFCA method against the H2SFCA and MM2SFCA methods, we used a percentile grouping scheme to display the results of different methods. The results show that communities with high and very high accessibility are mainly distributed in various districts along the Yangtze River (e.g., Jiang'an, Jianghan, Qiaokou) and the nearby districts on the edge of the MDZ (e.g., Caidian, Hannan), which surround the schools. The communities with medium accessibility are mainly distributed outside the high value areas along the Yangtze River. The communities with low and very low accessibility are mainly distributed in the districts on the edge of the MDZ, such as Xinzhou, Huangpi, Dongxihu, etc. Almost all communities (except Shuangdun) have access to high schools.

Community-level accessibility was also calculated using the H2SFCA and MM2SFCA methods. Table 4 shows the descriptive statistics of these results compared to the proposed method, MMH2SFCA. The mean and standard deviation of the results of MMH2SFCA are greater than those of MM2SFCA, H2SFCA-Bike, and H2SFCA-Car, and less than those of the H2SFCA-Walk and H2SFCA-PT methods. Figure 6 illustrates the accessibility map obtained by the H2SFCA-Walk, H2SFCA-Bike, H2SFCA-PT, H2SFCA-Car, and MM2SFCA methods, as well as the relative difference of accessibility as a percentage compared to the results of the MMH2SFCA method.

Table 4. Descriptive statistics of accessibility results.

Method	Mean	Std
MMH2SFCA	0.973	1.501
MM2SFCA	0.806	0.524
H2SFCA-Walk	1.011	3.329
H2SFCA-Bike	0.965	1.441
H2SFCA-PT	1.035	2.635
H2SFCA-Car	0.938	1.329

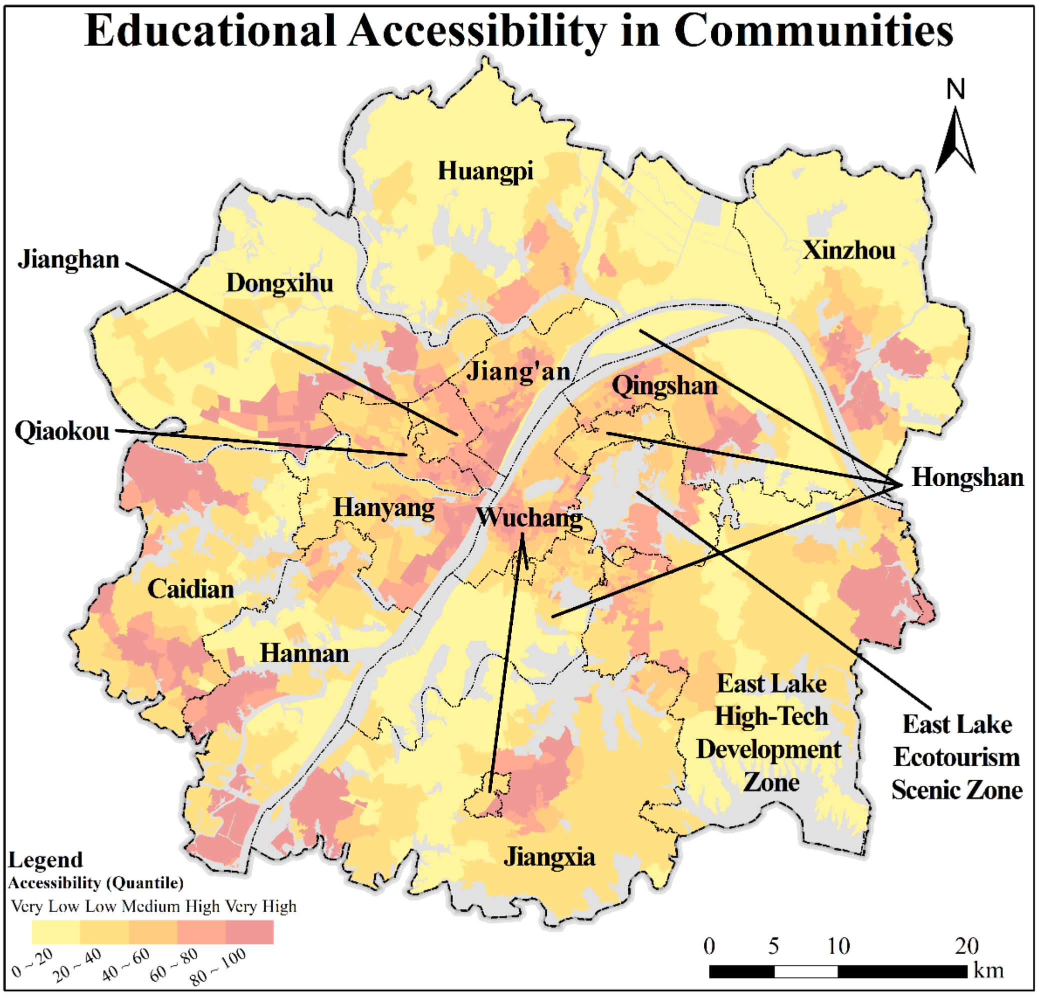

Figure 5. Educational accessibility in communities based on the MMH2SFCA method.

The results obtained using the H2SFCA method show that there are a large number of communities inaccessible to high schools by walking, biking, and PT. Communities with access to high schools by PT are fragmented due to the dependence on routes. However, H2SFCA-Car and MM2SFCA indicate that all communities, except for Shuangdun, have high accessibility to high schools. Communities with high accessibility based on H2SFCA-Car are concentrated in the districts located along the edge of the MDZ, whereas MM2SFCA indicates that communities with high accessibility are mostly concentrated in the urban center. The difference panels clearly show that, compared to the MMH2SFCA method, the H2SFCA-Walk, H2SFCA-Bike and H2SFCA-PT methods underestimate the accessibility of many communities in the districts located on the edge of the MDZ. In some communities near schools, walking and biking modes, based on H2SFCA, yield significantly greater accessibility than those by MMH2SFCA. Furthermore, H2SFCA-Car and MM2SFCA estimate higher accessibility than MMH2SFCA does in a large number of communities in the districts on the edge of the MDZ.

4.1.2. Gini Coefficient Comparison

In order to compare the equity degree of people's access to educational resources in different results, we used the Lorenz curve and Gini coefficient to measure the equity in the MDZ following existing equity research on green space accessibility [20,32]. The horizontal axis of a Lorenz curve represents the cumulative percentage of students based on an ascending order of accessibility. The vertical axis represents the cumulative percentage of education accessibility. Meanwhile, the Gini coefficient is the ratio of the area between the equality curve and Lorenz curve to the area under the equality curve [32]. The Gini coefficient ranges from 0 (perfect equity) to 1 (total inequality), with higher values indicating inequality. Figure 7a shows the Lorenz curves based on different accessibility methods. As can be seen, the Gini coefficient of MMH2SFCA is lower than those of H2SFCA-Walk, H2SFCA-Bike and H2SFCA-PT, but higher than those of H2SFCA-Car and MM2SFCA. This means that MMH2SFCA indicates higher equality than the H2SFCA method in terms of using the walking, biking, and PT modes, but lower equality than the H2SFCA method in terms of using a private car and the MM2SFCA method.

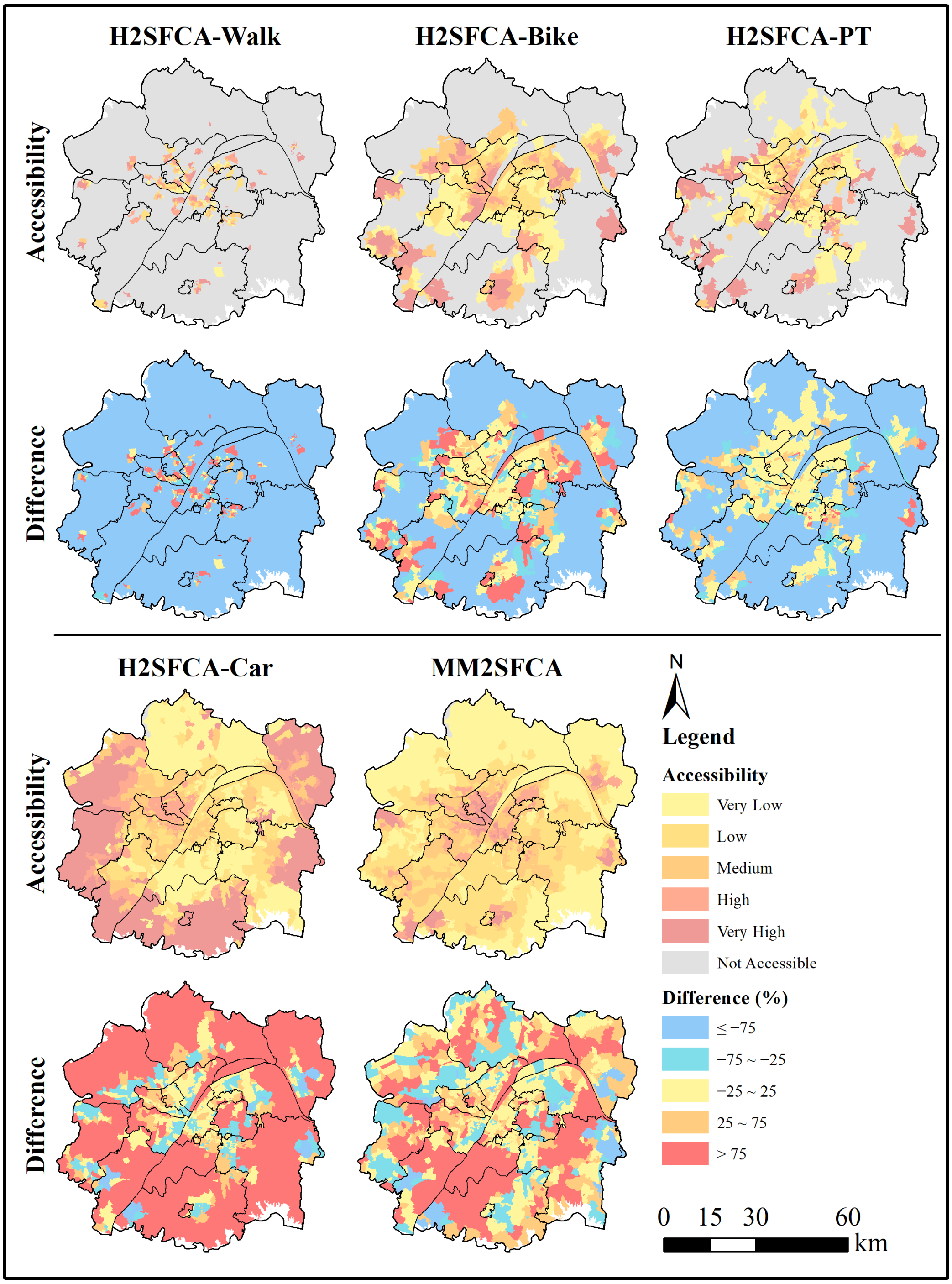

Figure 6. The results of the H2SFCA and MM2SFCA methods and their differences with MMH2SFCA.

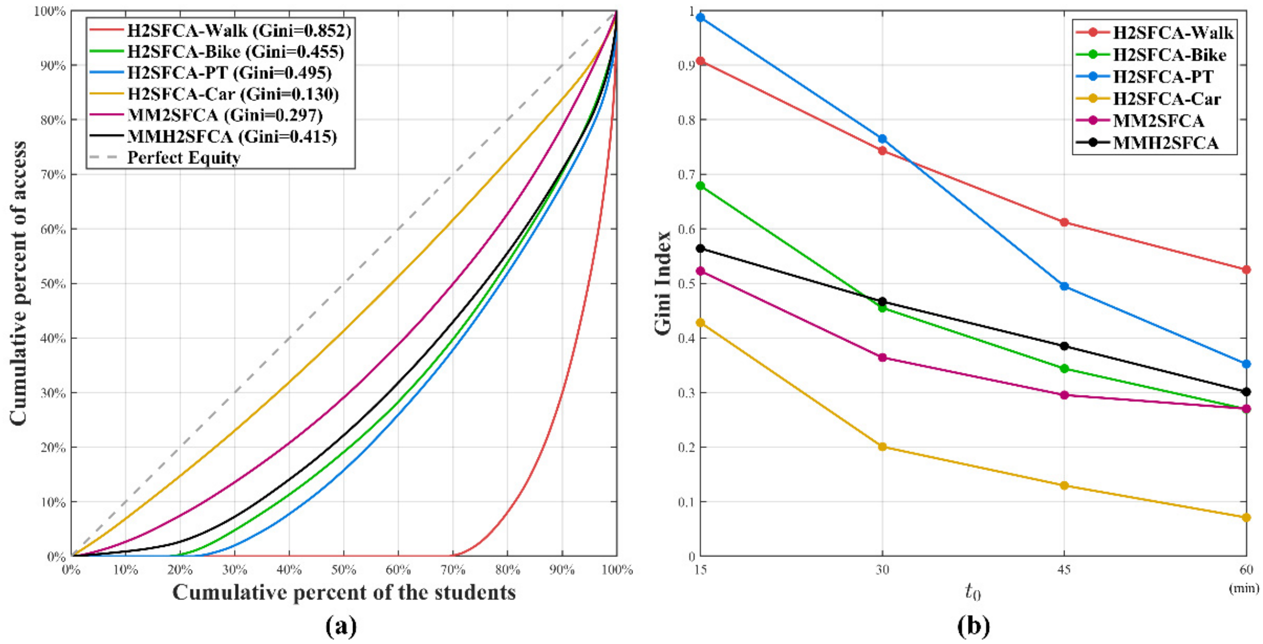

Figure 7. (**a**) Lorenz curves and Gini coefficients corresponding to the results of each method; (**b**) Variation of Gini coefficients with different methods and search radii.

In order to compare the accessibility equity using the MMH2SFCA method and existing 2SFCA method with different search radii, we evaluated the equity based on these methods using an identical series of search radii for each travel mode. Figure 7b shows the variation of Gini coefficients for each method and search radius. As the search radius increases, Gini coefficients decrease, thus indicating higher equality. The Gini coefficient based on MMH2SFCA is lower than those based on H2SFCA-Walk and H2SFCA-PT, but is higher than those based on H2SFCA-Car and MM2SFCA. MMH2SFCA also demonstrates a fairly stable rate of change.

4.2. Educational Accessibility and Quality

4.2.1. Spatial Distribution and Descriptive Statistics

Educational equity mainly has two aspects: accessibility equity and quality equity. Figure 5 shows accessibility based on MMH2SFCA, reflecting students' opportunities to access high schools in each community. Next, we measured the quality of education to which students in each community have access using the method mentioned in Section 4.1. Figure 8 shows the spatial distribution of the educational quality received by students in each community based on accessibility, which was obtained using the percentile color scheme. In contrast to educational accessibility, almost all communities where students can receive high-quality education are located in districts at the center of the MDZ (i.e., Jiang'an, Jianghan, and Wuchang). The majority of downtown communities have access to at least medium-quality education schools. Most of the communities in the districts on the edge of the MDZ only have access to high schools of low or very low quality, except for a few communities.

The statistical results show that the accessibility and quality of different regions present obvious disparity on the corresponding mean values, standard deviations, and Gini coefficients in different areas (see Table 5). For accessibility equity, areas with a higher mean value of accessibility are distributed in both the central and suburban areas. In particular, the mean values of some suburban areas (e.g., Jiangxia, Caidian, Hannan) are slightly higher than those of central urban areas. This can be attributed to the investments made in urban transportation and educational facilities in suburban areas in recent years. However, the standard deviations and Gini coefficients also show that the suburban areas have higher values than the central areas, indicating that although the accessibility of suburban areas is relatively good, the difference within the region is large, thus presenting obvious inequality. Moreover, although the mean value of accessibility is slightly lower in the central urban area, the standard deviations and Gini coefficients are smaller; thus, the accessibility of educational facilities within the region is relatively fair. For quality equity, communities with a higher mean value are mainly concentrated in central urban areas, especially in Jiang'an, Jianghan, and Wuchang. The main reason is that the city's high-level teachers and students as well as better investments in educational resources are all concentrated in these districts. Meanwhile, the regions with high Gini coefficients of education quality are mainly concentrated in suburban areas. This indicates that the education quality in suburban areas is relatively low, and the disparity among communities is slightly large, thus indicating that the education quality in suburban areas should be given more attention.

4.2.2. Correlation Analysis

We used bivariate analysis to further analyze the correlation of spatial patterns between educational accessibility and educational quality. Bivariate global Moran's I and bivariate local Moran's I can be used to describe the spatial correlation between the distribution patterns of two variables in the entire region and in different units within the same region [83].

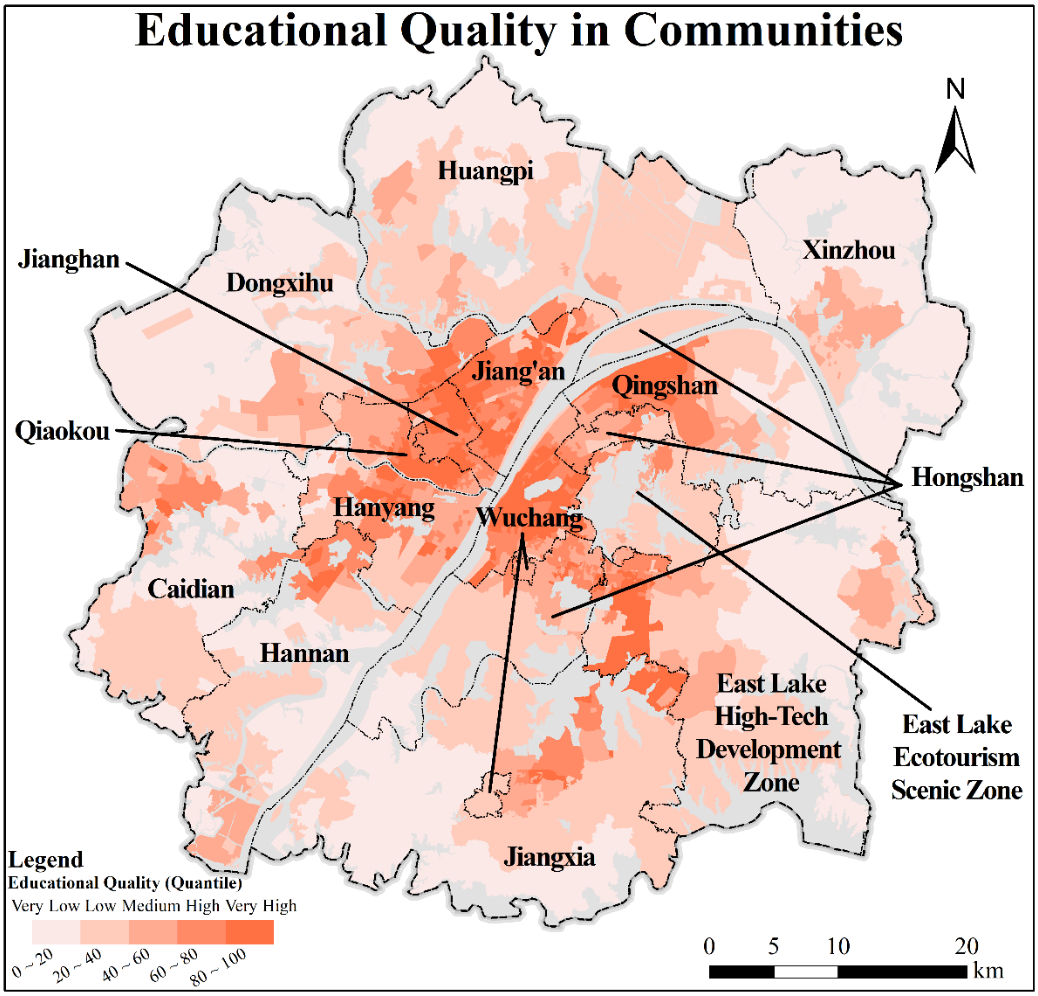

Figure 8. Educational quality in communities.

Table 5. Statistical results on educational accessibility and educational quality in each district.

Name	N	Accessibility			Quality		
		Mean	Std	Gini	Mean	Std	Gini
Jiang'an	187	1.164	0.709	0.260	0.447	0.091	0.138
Jianghan	117	1.195	0.477	0.181	0.448	0.070	0.139
Qiaokou	149	0.944	0.296	0.205	0.420	0.077	0.128
Hanyang	136	0.988	0.708	0.371	0.349	0.126	0.233
Wuchang	201	0.868	0.296	0.200	0.446	0.107	0.123
Qingshan	149	1.150	1.201	0.249	0.323	0.198	0.184
Hongshan	130	0.445	0.305	0.398	0.250	0.173	0.393
Dongxihu	109	0.815	0.946	0.412	0.170	0.169	0.340
Caidian	138	1.338	1.619	0.566	0.158	0.153	0.477
Jiangxia	130	1.556	3.581	0.614	0.157	0.179	0.442
Huangpi	136	0.140	0.239	0.519	0.059	0.078	0.436
Xinzhou	114	0.931	2.322	0.687	0.061	0.082	0.526
Hannan	69	1.238	1.934	0.604	0.151	0.171	0.513
East Lake High-Tech Development Zone	144	0.961	2.187	0.374	0.169	0.191	0.371
East Lake Ecotourism Scenic Zone	18	0.752	0.810	0.290	0.177	0.144	0.300
Total	1927	0.973	1.501	0.415	0.275	0.198	0.317

The global correlation of accessibility and quality in the MDZ is positive (I = 0.101) and significant (Z = 16.873, $p < 0.001$). Figure 9 shows local Moran's I, illustrating the spatial clusters and outliers of accessibility and quality at a local scale. There are five types of community clusters in terms of accessibility and quality: high accessibility–high quality (HH), high accessibility–low quality (HL), low accessibility–high quality (LH), low accessibility–low quality (LL), and insignificant. HH cluster communities are mainly distributed in the urban center located along the banks of the Yangtze River and the Han River or around several high-quality high schools. LL clusters are in areas with no schools in the districts located on the edge of the MDZ. LH clusters are adjacent to the periphery of HH clusters in the urban center. HL clusters concentrate around high schools with medium or low quality in the districts located on the edge of the MDZ. In particular, there is a ring area with insignificant spatial correlation in the gap between LH clusters in the periphery of the urban center and LL clusters in the districts on the edge of the MDZ.

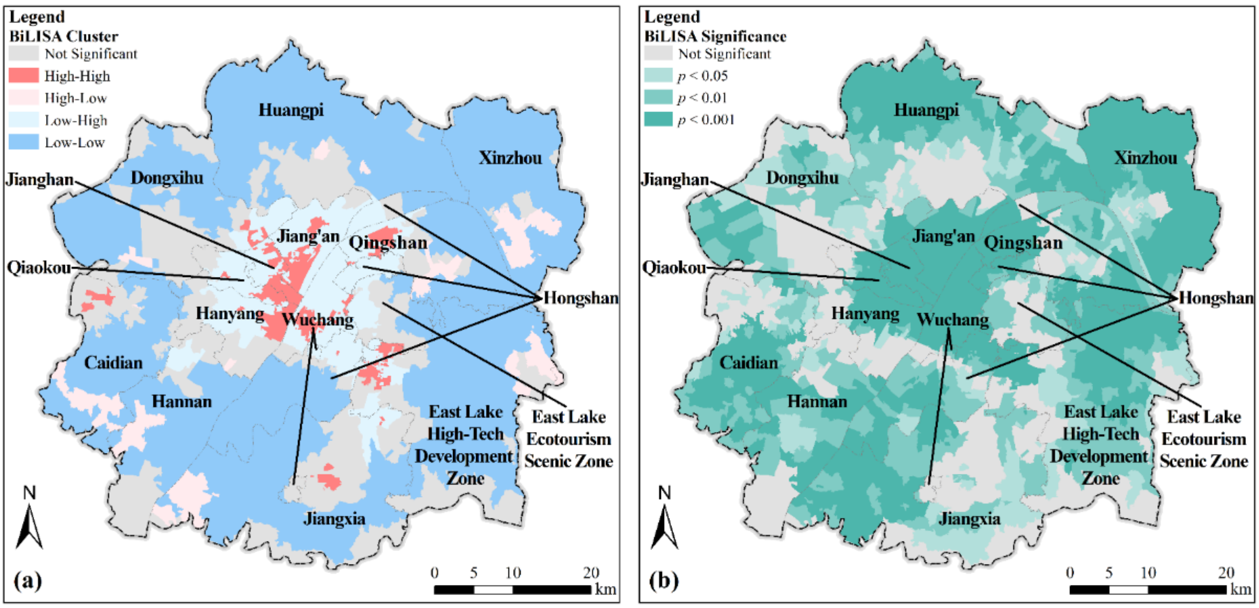

Figure 9. Local spatial correlations of education accessibility and quality. (**a**) Bivariate local Moran's I cluster map; (**b**) Bivariate local Moran's I significance map.

5. Discussion

5.1. Discussion on the Comparison of Methods

This study proposes MMH2SFCA, which is an approach to assess the accessibility of resources, while considering differences in travel mode and degree of attractiveness, which can influence people's choices. The proposed method combines the advantages of H2SFCA and MM2SFCA. By comparing MMH2SFCA with these methods, we conclude that the former avoids some disadvantages of existing 2SFCA methods to some extent.

5.1.1. Comparison with the H2SFCA Method

H2SFCA-Walk and H2SFCA-Bike assume that people can only use one travel mode, walking or biking, which obviously underestimates people's travel ability. Students cannot get to distant schools within a tolerable length of time, which leads to inaccessibility in many communities. Therefore, the accessibility of these communities is underestimated. The spatial distribution of the results is similar to that of the case study conducted by Dony et al. [84]. At the same time, as a large number of communities cannot reach schools within the time allowed, educational resources in the method are occupied by a small number of communities, and the accessibility of these communities is overestimated. The overall result is the unfair distribution of educational resources.

Meanwhile, the results of the H2SFCA-PT method are related to PT lines. The mobility of the PT mode is not as flexible as that of the other three modes [85]. This results in the underestimation of accessibility in a large number of communities far away from stations as well as the overestimation of the number of communities that can quickly reach schools through PT. The overall result is reflected in the unfair distribution of educational resource accessibility. The H2SFCA-Car method believes that people only use private cars to travel, which overestimates people's travel ability [48,86] and assumes that students can go to distant schools in a relatively short time and that more communities can share educational resources in a larger area. The results of the H2SFCA-Car method indicate that the distribution of educational resources' accessibility is equitable. This is because the schools in several districts in the center of the MDZ can be reached by more communities within a tolerable period of time and because the educational resources will be shared by more communities. Schools with higher quality are mostly distributed in the urban center, and students are more inclined to choose these schools. This aggravates the pressure on the supply of educational resources for these schools in the urban center. Moreover, the traffic pressure in the urban center is higher, while the roads in remote districts are relatively smoother. Finally, the result of the H2SFCA-Car method shows that most of the regions with high accessibility are distributed along the edge of the MDZ.

In general, the H2SFCA method of a single travel mode is more likely to overestimate or underestimate some communities or show some extreme cases. This bias is particularly obvious for remote communities or those in the vicinity of schools. The evaluation results of educational accessibility with this method are largely influenced by the mode of travel used by the students.

5.1.2. Comparison with the MM2SFCA Method

Although the MM2SFCA method considers multiple travel modes [48], it does not introduce the competition mechanism. In the case that a community is slightly closer to low-quality schools than to high-quality schools, students are more likely to consider the travel cost and prefer the low-quality schools. This will reduce the pressure of supply and demand for high-quality schools, while the utilization rate of low-quality schools will increase. In other words, without competition, the difference between schools' supply and demand is reduced, resulting in a decreased contrast between communities' levels of accessibility. The final result is the equitable distribution of educational resources. However, using this method may miss the areas with low accessibility and overestimate the equitable level.

5.1.3. Advantages of Our Proposed Method

Compared with the H2SFCA method, MMH2SFCA avoids underestimating people's travel ability when only using the walking or biking modes of transportation. It avoids the optimistic overestimation of people's ability to travel when using car alone and the over-reliance on PT lines when using the PT mode only. Therefore, the proposed method can be used to measure accessibility in a more realistic way, which confirms the findings of past relevant studies [48,70]. Compared with the MM2SFCA method, the MMH2SFCA method considers the attractiveness of schools and avoids unreasonable school choices based only on distance.

Our results appear to be contrary to previous findings, which indicate that mean and standard deviations of single-mode accessibility methods are slightly higher than those of multi-mode accessibility methods [70]. This may be due to the fact that our method uses different search radii for different travel modes. This suggests that some problems should be given attention in future research. Meanwhile, with the increase in the search radius, the results of each 2SFCA method become more equitable (Figure 7b). This confirms the theory that "on a smaller spatial scale, the inequality of facility provision is more obvious" [87]. In addition, compared with previous studies using capacity as a single metric of facility attractiveness [49], the current study measures the attractiveness from several aspects, including education resource pressure (Teacher–Student Ratio), education outcome (Excellent School Acceptance Rate), social popularity (School Hot), and the government's rating (School Level). They can better evaluate the education quality of a school rather than capacity, which has less obvious contrast, and has fewer gradients.

5.2. Implications and Recommendations

Some previous studies have discussed the educational inequities in compulsory education in some large cities in China using household registration, housing, and other factors [12,67]. The current paper studies the educational equity of non-compulsory education in Wuhan through accessibility measurement. Our findings suggested that the distribution of educational accessibility and educational quality in Wuhan is inequitable. The accessibility of educational resources presents a multi-center pattern. The accessibility levels of the urban center communities along the two rivers and around the schools located along the edge of the MDZ are high. In comparison, the accessibility levels of communities in the outer ring of the urban center and those far away from schools in districts on the edge of the MDZ are low. Meanwhile, the quality of education is a single-center model with a high urban center and low edge of the MDZ.

Such a distribution is the result of a combination of policy, historical, economic and urban development factors. First of all, some early policies, such as "urban bias" and "key schools and universities", artificially caused the concentration of excellent educational resources [88,89]. Furthermore, high-quality educational resources are also concentrated in "key" or "private" schools [12,72,88]. Additionally, if decision-makers only pay attention to the total demand of the whole city, but do not address the demand of residents in the inner region of the city, the distribution gap in the region will be covered up [90]. Under these circumstances, urban public policy deviation may appear and resources may mostly be concentrated in the urban center, new developing areas or other priority areas [91]. Second, a school (except for certain policies or capital support) needs a long time before it can have a higher quality of education. Therefore, most high-quality high schools have been established for a longer time than others and have developed together with city development. With the exception of some relocations, most high-quality schools are in the city center [12]. Third, the level of economic development in the city center is relatively higher compared to other areas, and people's demand for high-quality education is more urgent. For example, housing prices around schools are related to school quality [12]. Therefore, the intensity of education construction and the amount of investments made in the urban center are greater than those in the new development areas, such as the districts on the edge of the MDZ, thus forming a situation where the stronger becomes even stronger. In addition, there are differences in traffic construction between the districts in the urban center and those on the edge of the MDZ, and people have varying commuting abilities in different areas. A related study shows that road traffic conditions on the way to school have a significant impact on students' daily commute [74]. The urban center is often an area with the most convenient transportation in a city; thus, there are better transportation conditions for students to go to school and even those from distant communities can quickly reach their schools. Therefore, the communities in the urban center not too far from the high-quality schools form HH clusters, and the more distant communities form LH clusters. In the districts on the edge of the MDZ, most of the communities form LL clusters due to the lack of high-quality schools and inconvenient transportation. A few communities close to schools are limited by the low quality of schools, thus forming HL clusters.

The government has issued many policies to promote educational equity [92–96]. To improve the equity of educational accessibility, our findings suggested one effective way is not only to increase new schools, but also to improve the public transport system in remote areas. According to the survey data, most of the high school students in the MDZ use PT to go to school. Therefore, the government can add new lines and stops in remote areas to improve the coverage of PT. Urban planners can also optimize the road traffic in the main urban area to improve the efficiency of commuting. The most basic way to improve the equity of educational quality is to balance the distribution of high-quality schools among different districts, not merely making policies to improve the overall educational quality [97,98]. By allocating resources of similar quality to public schools, increasing investment and support for poor performing schools, or by sharing high-quality teacher resources, the gap between school teaching quality can be narrowed, thus reducing competition among high-quality schools [13]. In addition, there is a transitivity between high-quality compulsory education and high-quality non-compulsory education. Although non-compulsory education adopts a preferential admission policy, students who are enrolled in high-quality junior high schools are more likely to achieve good grades and enter high-quality high schools [99]. Therefore, the quota enrollment policy [92], in which high-quality high schools can recruit a certain number of students from junior high schools with poor performance, may alleviate the situation of educational inequality. It may also be helpful in improving the equity of the quality of compulsory education, as more students will have equal access to high-quality high schools.

5.3. Limitations

Our case study reveals several limitations of the proposed method. First of all, as high school education is not compulsory, students who want to enter high-quality schools must pass the selection criteria of each school or pay a certain fee [12]. The proposed method, however, does not consider this phenomenon. In this study, all students are considered equal, and the accessibility to enter high school only depends on the mode of travel, the cost of travel, and the attractiveness of the school, without considering the students' academic performance and the socioeconomic statuses of their families. Second, the travel cost of students is the shortest time consumption of web map navigation. Although this method is more practical than network analysis based on the road network and the average speed of different travel modes, the students' travel routes are actually much more complicated and do not necessarily adopt the least time-consuming route. Such complexity may result in less heterogeneity of accessibility in the proposed method's results than in the actual situation [48]. Third, our method also suffers from edge effects as with other methods [48,52]. Students in marginal areas are more likely to choose schools outside the MDZ, and because the communities outside the MDZ are not taken into account, the supply–demand ratio of marginal schools may be overestimated. This may lead to abnormal results of the accessibility of marginal communities. In the future, we will conduct more in-depth research on these issues.

6. Conclusions

This paper proposes an accessibility method called MMH2SFCA, which comprehensively considers the attractiveness of schools and multiple travel modes. Compared with the existing 2SFCA methods, this method combines the advantages of the existing 2SFCA method and improves the unreasonable assumption that residents travel in a single mode and all facilities are completely consistent. Our method uses multiple travel modes, which is more realistic than the single travel mode in the H2SFCA method. School attraction calculation is more reasonable than using capacity to represent the school's impact on students. Additionally, the introduction of school attraction is also an improvement on the MM2SFCA method, which adopts multiple travel modes but ignores the differences of facilities. It can measure the accessibility of educational resources more reliably. At the same time, the travel time obtained by using navigation data is more real than that obtained by using road network data through network analysis, and the questionnaire survey also provides a reliable basis for the setting of method parameters. We also extend the concept of accessibility to calculate the education quality of each community. It overcomes the deficiency that the existing 2SFCA can only consider the quantity of resources or services that residents obtain, but ignore the quality of resources or services that residents obtain. In general, our method can effectively detect the areas with insufficient educational resources on the scale of the community. This may help decision-makers develop region-specific policies based on their needs to avoid resource concentration in priority areas such as the urban center caused by only considering the overall demand of the city.

The spatial distribution of education accessibility and quality of students in the MDZ of Wuhan is inequitable. The accessibility is higher in the urban centers along the two rivers and around the schools on the edge of the MDZ, while it is low in communities far away from schools. However, the communities that can obtain higher education quality are mainly concentrated in the urban center, but quality is lower in other areas. This indicates a spatial mismatch between educational accessibility and quality. Economic development, urban expansion and the corresponding problems left over by historical policies were regarded as the common factors jointly resulting in the inequity of educational accessibility and quality. It is common that schools are concentrated in urban centers and new development areas with preferential policies, and high-quality educational resources are also concentrated in "key" or "private" schools. Our research reveals the need for policies of equity in educational resources. Policies need to ensure equity in both the accessibility and quality of education. In addition to existing policies, there are some alternative ways to improve equity in education, such as to improve public transport services in remote areas and enrich urban traffic patterns in the urban center, to allocate equal resources with the same quality to schools, to support vulnerable schools vigorously, etc. The evaluation method proposed in our study maybe provides a reliable reference for decision-makers.

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

Appendix A

A Questionnaire Survey on the Way Senior High School Students Go to School in Wuhan

1. What is your gender?
    - A. Male
    - B. Female
2. What is your age? (Please fill in your age value.)
3. Where are you from? (Please select a specific province-city-district.)
4. Where is your high school? (Please select a specific province-city-district, if you do not attend high school, please select your birthplace.)
5. What is your usual way to go to school in high school? (If you have never been to high school, please select "Other".)
    - A. Walking
    - B. Bicycle/Electric vehicle
    - C. Bus/Subway
    - D. Private car
    - E. Other
6. What is your average time on the way to school in high school? (If you have never been to high school, please choose the usual commuting time.)
    - A. Less than 10 min
    - B. 10–20 min
    - C. 20–30 min
    - D. 30–45 min
    - E. 45–60 min
    - F. 1–2 h
    - G. More than 2 h
7. What is your usual way of commuting to work/school?
    - A. Walking
    - B. Bicycle/Electric vehicle
    - C. Bus/Subway
    - D. Private car
    - E. Other
8. What is the average time you spend on your way to work/school?
    - A. Less than 10 min
    - B. 10–20 min
    - C. 20–30 min
    - D. 30–45 min
    - E. 45–60 min
    - F. 1–2 h
    - G. More than 2 h

Online questionnaire URL: https://wj.qq.com/s2/7165155/8a88 (accessed on 3 July 2021).

References

1. UNESCO. *Education 2030: Incheon Declaration and Framework for Action for the implementation of Sustainable Development Goal 4: Ensure Inclusive and Equitable Quality Education and Promote Lifelong Learning Opportunities for All*; United Nations Educational, Scientific and Cultural Organization: Paris, France, 2016; p. 86.
2. Gao, Y.; He, Q.; Liu, Y.; Zhang, L.; Wang, H.; Cai, E. Imbalance in Spatial Accessibility to Primary and Secondary Schools in China: Guidance for Education Sustainability. *Sustainability* **2016**, *8*, 1236. [CrossRef]
3. Zhao, D.; Parolin, B. Merged or Unmerged School? School Preferences in the Context of School Mapping Restructure in Rural China. *Asia Pac. Educ. Res.* **2013**, *23*, 547–563. [CrossRef]

4. Vaught, S.E. The Color of Money: School Funding and the Commodification of Black Children. *Urban Educ.* **2009**, *44*, 545–570. [CrossRef]
5. Knight, D.S. Are School Districts Allocating Resources Equitably? The Every Student Succeeds Act, Teacher Experience Gaps, and Equitable Resource Allocation. *Educ. Policy* **2017**, *33*, 615–649. [CrossRef]
6. Halai, A. Equality or equity: Gender awareness issues in secondary schools in Pakistan. *Int. J. Educ. Dev.* **2011**, *31*, 44–49. [CrossRef]
7. Meschi, E.; Scervini, F. A new dataset on educational inequality. *Empir. Econ.* **2014**, *47*, 695–716. [CrossRef]
8. Kyriakides, L.; Creemers, B.P.; Charalambous, E. Searching for differential teacher and school effectiveness in terms of student socioeconomic status and gender: Implications for promoting equity. *Sch. Eff. Sch. Improv.* **2018**, *30*, 286–308. [CrossRef]
9. Luo, Y.; Zhou, R.Y.; Mizunoya, S.; Amaro, D. How various types of disabilities impact children's school attendance and completion—Lessons learned from censuses in eight developing countries. *Int. J. Educ. Dev.* **2020**, *77*, 102222. [CrossRef]
10. Van Dyk, H.; White, C. Theory and practice of the quintile ranking of schools in South Africa: A financial management perspective. *South. Afr. J. Educ.* **2019**, *39*, S1–S9. [CrossRef]
11. Caner, H.A.; Bayhan, S. High-stakes examination policies and transformation of the Turkish education system. *Int. J. Educ. Dev.* **2020**, *79*, 102263. [CrossRef]
12. Zhang, J.; Li, H.; Lin, J.; Zheng, W.; Li, H.; Chen, Z. Meta-analysis of the relationship between high quality basic education resources and housing prices. *Land Use Policy* **2020**, *99*, 104843. [CrossRef]
13. Hu, L.; He, S.; Luo, Y.; Su, S.; Xin, J.; Weng, M. A social-media-based approach to assessing the effectiveness of equitable housing policy in mitigating education accessibility induced social inequalities in Shanghai, China. *Land Use Policy* **2020**, *94*, 104513. [CrossRef]
14. Wen, H.; Xiao, Y.; Zhang, L. School district, education quality, and housing price: Evidence from a natural experiment in Hangzhou, China. *Cities* **2017**, *66*, 72–80. [CrossRef]
15. Hu, W.; Wang, R. Segregation in urban education: Evidence from public schools in Shanghai, China. *Cities* **2019**, *87*, 106–113. [CrossRef]
16. Churchill, S.A.; Smyth, R. Transport poverty and subjective wellbeing. *Transp. Res. Part A Policy Pr.* **2019**, *124*, 40–54. [CrossRef]
17. Allen, J.; Farber, S. Planning transport for social inclusion: An accessibility-activity participation approach. *Transp. Res. Part D Transp. Environ.* **2020**, *78*, 102212. [CrossRef]
18. Wang, H.; Kwan, M.-P.; Hu, M. Social exclusion and accessibility among low- and non-low-income groups: A case study of Nanjing, China. *Cities* **2020**, *101*, 102684. [CrossRef]
19. Tsou, K.-W.; Hung, Y.-T.; Chang, Y.-L. An accessibility-based integrated measure of relative spatial equity in urban public facilities. *Cities* **2005**, *22*, 424–435. [CrossRef]
20. 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]
21. Dai, D. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. *Health Place* **2010**, *16*, 1038–1052. [CrossRef] [PubMed]
22. Dai, D. Racial/ethnic and socioeconomic disparities in urban green space accessibility: Where to intervene? *Landsc. Urban Plan.* **2011**, *102*, 234–244. [CrossRef]
23. Kunzmann, K.R. Planning for spatial equity in Europe. *Int. Plan. Stud.* **1998**, *3*, 101–120. [CrossRef]
24. Ashik, F.R.; Alam Mim, S.; Neema, M.N. Towards vertical spatial equity of urban facilities: An integration of spatial and aspatial accessibility. *J. Urban Manag.* **2020**, *9*, 77–92. [CrossRef]
25. Litman, T. *Evaluating Transportation Equity: Guidance for Incorporating Distributional Impacts in Transportation Planning*; Victoria Transport Policy Institute: Victoria, British, 2006; p. 8.
26. Ricciardi, A.M.; Xia, J.; Currie, G. Exploring public transport equity between separate disadvantaged cohorts: A case study in Perth, Australia. *J. Transp. Geogr.* **2015**, *43*, 111–122. [CrossRef]
27. Wang, S.-I.; Yaung, C.-L. Vertical equity of healthcare in Taiwan: Health services were distributed according to need. *Int. J. Equity Health* **2013**, *12*, 12. [CrossRef] [PubMed]
28. Yuan, Y.; Xu, J.; Wang, Z. Spatial Equity Measure on Urban Ecological Space Layout Based on Accessibility of Socially Vulnerable Groups—A Case Study of Changting, China. *Sustainability* **2017**, *9*, 1552. [CrossRef]
29. Dadashpoor, H.; Rostami, F.; Alizadeh, B. Is inequality in the distribution of urban facilities inequitable? Exploring a method for identifying spatial inequity in an Iranian city. *Cities* **2016**, *52*, 159–172. [CrossRef]
30. Chen, Z.; Guo, Y.; Stuart, A.L.; Zhang, Y.; Li, X. Exploring the equity performance of bike-sharing systems with disaggregated data: A story of southern Tampa. *Transp. Res. Part A Policy Pr.* **2019**, *130*, 529–545. [CrossRef]
31. Panagiotopoulos, G.; Kaliampakos, D. Accessibility and Spatial Inequalities in Greece. *Appl. Spat. Anal. Policy* **2018**, *12*, 567–586. [CrossRef]
32. Guo, S.; Song, C.; Pei, T.; Liu, Y.; Ma, T.; Du, Y.; Chen, J.; Fan, Z.; Tang, X.; Peng, Y.; et al. Accessibility to urban parks for elderly residents: Perspectives from mobile phone data. *Landsc. Urban Plan.* **2019**, *191*, 103642. [CrossRef]
33. Rosas-Satizábal, D.; Guzman, L.A.; Oviedo, D. Cycling diversity, accessibility, and equality: An analysis of cycling commuting in Bogotá. *Transp. Res. Part D Transp. Environ.* **2020**, *88*, 102562. [CrossRef]

34. Palm, M.; Farber, S. The role of public transit in school choice and after-school activity participation among Toronto high school students. *Travel Behav. Soc.* **2020**, *19*, 219–230. [CrossRef]
35. Chen, N.; Wang, C.-H. Does green transportation promote accessibility for equity in medium-size U.S. cites? *Transp. Res. Part D Transp. Environ.* **2020**, *84*, 102365. [CrossRef]
36. Kelobonye, K.; Zhou, H.; McCarney, G.; Xia, J. (Cecilia) Measuring the accessibility and spatial equity of urban services under competition using the cumulative opportunities measure. *J. Transp. Geogr.* **2020**, *85*, 102706. [CrossRef]
37. Taleai, M.; Sliuzas, R.; Flacke, J. An integrated framework to evaluate the equity of urban public facilities using spatial multi-criteria analysis. *Cities* **2014**, *40*, 56–69. [CrossRef]
38. Hansen, W.G. How Accessibility Shapes Land Use. *J. Am. Inst. Plan.* **1959**, *25*, 73–76. [CrossRef]
39. Saurman, E. Improving access: Modifying Penchansky and Thomas's Theory of Access. *J. Health Serv. Res. Policy* **2016**, *21*, 36–39. [CrossRef] [PubMed]
40. Bantis, T.; Haworth, J. Assessing transport related social exclusion using a capabilities approach to accessibility framework: A dynamic Bayesian network approach. *J. Transp. Geogr.* **2020**, *84*, 102673. [CrossRef]
41. Vallée, J.; Shareck, M.; Le Roux, G.; Kestens, Y.; Frohlich, K.L. Is accessibility in the eye of the beholder? Social inequalities in spatial accessibility to health-related resources in Montréal, Canada. *Soc. Sci. Med.* **2020**, *245*, 112702. [CrossRef]
42. Moore, L.V.; Roux, A.V.D.; Evenson, K.R.; McGinn, A.P.; Brines, S.J. Availability of Recreational Resources in Minority and Low Socioeconomic Status Areas. *Am. J. Prev. Med.* **2008**, *34*, 16–22. [CrossRef]
43. Boone, C.G.; Buckley, G.L.; Grove, J.M.; Sister, C. Parks and People: An Environmental Justice Inquiry in Baltimore, Maryland. *Ann. Assoc. Am. Geogr.* **2009**, *99*, 767–787. [CrossRef]
44. Yang, L.; Wang, B.; Zhou, J.; Wang, X. Walking accessibility and property prices. *Transp. Res. Part D Transp. Environ.* **2018**, *62*, 551–562. [CrossRef]
45. Hu, L. Racial/ethnic differences in job accessibility effects: Explaining employment and commutes in the Los Angeles region. *Transp. Res. Part D Transp. Environ.* **2019**, *76*, 56–71. [CrossRef]
46. 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. Plan. B Plan. Des.* **2003**, *30*, 865–884. [CrossRef] [PubMed]
47. 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]
48. Mao, L.; Nekorchuk, D. Measuring spatial accessibility to healthcare for populations with multiple transportation modes. *Health Place* **2013**, *24*, 115–122. [CrossRef]
49. Luo, J. Integrating the Huff Model and Floating Catchment Area Methods to Analyze Spatial Access to Healthcare Services. *Trans. GIS* **2014**, *18*, 436–448. [CrossRef]
50. Tao, Z.; Cheng, Y.; Dai, T.; Rosenberg, M.W. Spatial optimization of residential care facility locations in Beijing, China: Maximum equity in accessibility. *Int. J. Health Geogr.* **2014**, *13*, 33. [CrossRef]
51. Dai, D.; Wang, F. Geographic disparities in accessibility to food stores in southwest Mississippi. *Environ. Plan. B Plan. Des.* **2011**, *38*, 659–677. [CrossRef]
52. Luo, W.; Whippo, T. Variable catchment sizes for the two-step floating catchment area (2SFCA) method. *Health Place* **2012**, *18*, 789–795. [CrossRef]
53. McGrail, M.R.; Humphreys, J.S. Measuring spatial accessibility to primary health care services: Utilising dynamic catchment sizes. *Appl. Geogr.* **2014**, *54*, 182–188. [CrossRef]
54. 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]
55. Fransen, K.; Neutens, T.; De Maeyer, P.; Deruyter, G. A commuter-based two-step floating catchment area method for measuring spatial accessibility of daycare centers. *Health Place* **2015**, *32*, 65–73. [CrossRef]
56. Ma, X.; Ren, F.; Du, Q.; Liu, P.; Li, L.; Xi, Y.; Jia, P. Incorporating multiple travel modes into a floating catchment area framework to analyse patterns of accessibility to hierarchical healthcare facilities. *J. Transp. Health* **2019**, *15*, 100675. [CrossRef]
57. Zhou, X.; Yu, Z.; Yuan, L.; Wang, L.; Wu, C. Measuring Accessibility of Healthcare Facilities for Populations with Multiple Transportation Modes Considering Residential Transportation Mode Choice. *ISPRS Int. J. Geo Inf.* **2020**, *9*, 394. [CrossRef]
58. Cao, H. Spatial inequality in children's schooling in Gansu, Western China: Reality and challenges. *Can. Geogr.* **2008**, *52*, 331–350. [CrossRef]
59. Behbahani, H.; Nazari, S.; Kang, M.J.; Litman, T. A conceptual framework to formulate transportation network design problem considering social equity criteria. *Transp. Res. Part A Policy Pr.* **2019**, *125*, 171–183. [CrossRef]
60. Kelobonye, K.; McCarney, G.; Xia, J.; Swapan, M.S.H.; Mao, F.; Zhou, H. Relative accessibility analysis for key land uses: A spatial equity perspective. *J. Transp. Geogr.* **2019**, *75*, 82–93. [CrossRef]
61. Williams, S.; Fahui, W. Disparities in accessibility of public high schools, in metropolitan Baton Rouge, Louisiana 1990–2010. *Urban Geogr.* **2014**, *35*, 1066–1083. [CrossRef]
62. Singleton, A.D.; Longley, P.A.; Allen, R.; O'Brien, O. Estimating secondary school catchment areas and the spatial equity of access. *Comput. Environ. Urban Syst.* **2011**, *35*, 241–249. [CrossRef]
63. Boussauw, K.; van Meeteren, M.; Witlox, F. Short trips and central places: The home-school distances in the Flemish primary education system (Belgium). *Appl. Geogr.* **2014**, *53*, 311–322. [CrossRef]

64. Boterman, W.; Musterd, S.; Pacchi, C.; Ranci, C. School segregation in contemporary cities: Socio-spatial dynamics, institutional context and urban outcomes. *Urban Stud.* **2019**, *56*, 3055–3073. [CrossRef]
65. Scott, M.R.; Marshall, D.T. Public Transit and School Choice in Philadelphia: Exploring Spatial Equity and Social Exclusion. *J. Sch. Choice* **2018**, *13*, 177–197. [CrossRef]
66. Talen, E. School, Community, and Spatial Equity: An Empirical Investigation of Access to Elementary Schools in West Virginia. *Ann. Assoc. Am. Geogr.* **2001**, *91*, 465–486. [CrossRef]
67. Xiang, L.; Stillwell, J.; Burns, L.; Heppenstall, A.; Norman, P. A geodemographic classification of sub-districts to identify education inequality in Central Beijing. *Comput. Environ. Urban Syst.* **2018**, *70*, 59–70. [CrossRef]
68. Burger, K. The socio-spatial dimension of educational inequality: A comparative European analysis. *Stud. Educ. Eval.* **2019**, *62*, 171–186. [CrossRef]
69. Qian, H.; Walker, A.D. The education of migrant children in Shanghai: The battle for equity. *Int. J. Educ. Dev.* **2015**, *44*, 74–81. [CrossRef]
70. 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]
71. Feng, H.; Lu, M. School quality and housing prices: Empirical evidence from a natural experiment in Shanghai, China. *J. Hous. Econ.* **2013**, *22*, 291–307. [CrossRef]
72. Wu, Y.; Zheng, X.; Sheng, L.; You, H. Exploring the Equity and Spatial Evidence of Educational Facilities in Hangzhou, China. *Soc. Indic. Res.* **2020**, *151*, 1075–1096. [CrossRef]
73. Ye, C.; Zhu, Y.; Yang, J.; Fu, Q. Spatial equity in accessing secondary education: Evidence from a gravity-based model. *Can. Geogr. Le Géographe Can.* **2018**, *62*, 452–469. [CrossRef]
74. Gao, Y.; Chen, X.; Shan, X.; Fu, Z. Active commuting among junior high school students in a Chinese medium-sized city: Application of the theory of planned behavior. *Transp. Res. Part F Traffic Psychol. Behav.* **2018**, *56*, 46–53. [CrossRef]
75. Ngware, M.W.; Oketch, M.; Ezeh, A.C. Quality of Primary Education Inputs in Urban Schools: Evidence From Nairobi. *Educ. Urban Soc.* **2010**, *43*, 91–116. [CrossRef]
76. Diakoulaki, D.; Mavrotas, G.; Papayannakis, L. Determining objective weights in multiple criteria problems: The critic method. *Comput. Oper. Res.* **1995**, *22*, 763–770. [CrossRef]
77. Jahan, A.; Mustapha, F.; Sapuan, S.M.; Ismail, Y.; Bahraminasab, M. A framework for weighting of criteria in ranking stage of material selection process. *Int. J. Adv. Manuf. Technol.* **2012**, *58*, 411–420. [CrossRef]
78. Huff, D.L. A Probabilistic Analysis of Shopping Center Trade Areas. *Land Econ.* **1963**, *39*, 81. [CrossRef]
79. Tao, Z.; Cheng, Y. Research progress of the two-step floating catchment area method and extensions. *Prog. Geogr.* **2016**, *35*, 589–599.
80. 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]
81. Jing, Y.; Liu, Y.; Cai, E.; Liu, Y.; Zhang, Y. Quantifying the spatiality of urban leisure venues in Wuhan, Central China—GIS-based spatial pattern metrics. *Sustain. Cities Soc.* **2018**, *40*, 638–647. [CrossRef]
82. Wuhan Municipal People's Government. The Comprehensive Planning of Wuhan (2010–2020). Hongshan Branch of Wuhan Natural Resources and Planning Bureau 2010, 28 March 2015. Available online: http://gtghj.wuhan.gov.cn/hs/pc-994-77999.html (accessed on 3 July 2021).
83. Anselin, L. Local Indicators of Spatial Association-LISA. *Geogr. Anal.* **1995**, *27*, 93–115. [CrossRef]
84. Dony, C.C.; Delmelle, E.M.; Delmelle, E.C. Re-Conceptualizing Accessibility to Parks in Multi-Modal Cities: A Variable-Width Floating Catchment Area (VFCA) Method. *Landsc. Urban Plan.* **2015**, *143*, 90–99. [CrossRef]
85. Langford, M.; Higgs, G.; Fry, R. Multi-modal two-step floating catchment area analysis of primary health care accessibility. *Health Place* **2016**, *38*, 70–81. [CrossRef]
86. Wan, N.; Zhan, F.B.; Zou, B.; Chow, E. A relative spatial access assessment approach for analyzing potential spatial access to colorectal cancer services in Texas. *Appl. Geogr.* **2012**, *32*, 291–299. [CrossRef]
87. Tan, P.Y.; Samsudin, R. Effects of spatial scale on assessment of spatial equity of urban park provision. *Landsc. Urban Plan.* **2017**, *158*, 139–154. [CrossRef]
88. Huang, B.; He, X.; Xu, L.; Zhu, Y. Elite school designation and housing prices-quasi-experimental evidence from Beijing, China. *J. Hous. Econ.* **2020**, *50*, 101730. [CrossRef]
89. Bi, B. *Study on the Spatial Equity Evaluation and Planning Path of Urban Basic Education in Beijing*; Tsinghua University: Beijing, China, 2018.
90. 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]
91. 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]
92. Ministry of Education, PRC. Instructions to the Experimental Zoon of Basic Education Curriculum Reform, Middle School Graduation Exam, and High School Enrollment Policy Reform. Website of the Ministry of Education of the People's Republic of China 2005. 12 January 2005. Available online: http://www.moe.gov.cn/srcsite/A06/s3732/200501/t20050112_167346.html (accessed on 3 July 2021).

93. Xinhua News Agency. The CPC Central Committee and the State Council Issued the Medium and Long Term Youth Development Plan (2016–2025). Central People's Government of the People's Republic of China. 2017. Available online: http://www.gov.cn/zhengce/2017-04/13/content_5185555.htm (accessed on 3 July 2021).
94. General Office of the State Council. The Circular of the General Office of the State Council on Transmitting the Opinions of the Ministry of Education and Ether Departments on Migrant Workers' Children Taking Entrance Examination after Receiving Compulsory Education. Central People's Government of the People's Republic of China. 2012. Available online: http://www.gov.cn/zhengce/content/2012-08/31/content_5374.htm (accessed on 3 July 2021).
95. State Council. Opinions of the State Council on Further Promoting the Balanced Development of Compulsory Education. Central People's Government of the People's Republic of China. 2012. Available online: http://www.gov.cn/zhengce/content/2012-09/07/content_5339.htm (accessed on 3 July 2021).
96. State Council. Notice of the State Council on Printing and Distributing the 13th Five-Year Plan for the Development of National Education. Central People's Government of the People's Republic of China. 2017. Available online: http://www.gov.cn/zhengce/content/2017-01/19/content_5161341.htm (accessed on 3 July 2021).
97. Xinhua News Agency. Decision of the Central Committee of the Communist Party of China on Some Major Issues Concerning Comprehensively Deepening the Reform. Central People's Government of the People's Republic of China. 2013. Available online: http://www.gov.cn/zhengce/2013-11/15/content_5407874.htm (accessed on 3 July 2021).
98. General Office of the State Council. Notice of the General Office of the State Council on Printing and Distributing the Measures for Evaluating the Performance of Educational Responsibilities by Provincial People's Governments. Central People's Government of the People's Republic of China. 2017. Available online: http://www.gov.cn/zhengce/content/2017-06/08/content_5200756.htm (accessed on 3 July 2021).
99. Yu, Z.; Dongsheng, C.; Wen, W. The heterogeneous effects of ability grouping on national college entrance exam performance—Evidence from a large city in China. *Int. J. Educ. Dev.* **2014**, *39*, 80–91. [CrossRef]