



Article Spatial Distribution and Accessibility Analysis of Primary School Facilities in Mega Cities: A Case Study of Chengdu

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Abstract: High-quality and equitable primary education services promote the building of a harmonious socialist society and are an important basis for improving people's quality of life and promoting high-quality and sustainable regional development. Here, we take Chengdu City as a test area, integrate data from multiple sources, use the random forest model to simulate the distribution data of primary school-age children in Chengdu City in 2020, and use the kernel density estimation method and the multi-traffic mode two-stage floating catchment area method to measure the spatial distribution characteristics and accessibility of primary school educational facilities in Chengdu City and combine the imbalance index and spatial autocorrelation analysis, examination of the equalization of the distribution of primary school educational facilities, and the correlation between school-age population and accessibility. The results show that in the past decade, the population of Chengdu has grown rapidly, and the number of primary school-age children has also been increasing. The overall distribution of primary school-age children in Chengdu presents a decentralized pattern of "one point with multiple cores", with the population decreasing from the center to the periphery, and the population distribution dominates the spatial distribution of primary school facilities, which also highlights the imbalance in the construction of primary school facilities to some extent (S = 0.257), which was mainly manifested by the fact that the central-eastern part of the city has more primary school facilities, while the western part has fewer. In addition, the results of both accessibility and autocorrelation analyses show that the overall accessibility of the central circle of Chengdu was high, while the accessibility of the second and third circles was at a lower level and below, with very obvious cross-regional and cross-circle differences. This study can not only provide more accurate recommendations for the allocation of educational facilities but also serve as a reference for evaluating the spatial equity of other public services in the city.

Keywords: primary education facilities; accessibility; random forests; spatial autocorrelation

1. Introduction

Education is an essential "engine" for development and is crucial for achieving sustainable social progress [1]. The sustainable development of education can promote social equity and harmony by enhancing the fairness of educational resources and reducing educational inequality among regions and groups. As an essential component of the education system, the spatial distribution and accessibility of compulsory primary education play an important role in promoting educational equity and sustainable development.

The issue of education equity has always been extensively studied. Dai optimized the spatial distribution of schools using random mechanisms to ensure equal educational opportunities [2]; Al-Sabbagh employed the GIS location allocation model to enhance primary school enrollment opportunities in Mansura, Egypt [3]; Kim, in South Korea, evaluated the educational equity of rural commuting distances following the closure of



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Copyright: © 2024 by the authors. Licensee MDPI, Basel, Switzerland. This article is an open access article distributed under the terms and conditions of the Creative Commons Attribution (CC BY) license (https:// creativecommons.org/licenses/by/ 4.0/). elementary schools [4]; and Iraegui utilized qualified education accessibility to explore spatial equity [5].

Researching educational equity by assessing the actual accessibility of primary schools is an effective approach. Accessibility refers to the ease of obtaining services from a specific location via a transportation system. It evaluates the spatial interaction between service supply and demand, considering transportation costs, the appeal of supply-side services, and the distribution of demand-side services [6]. In 1959, Hanson introduced the concept of spatial accessibility and used it to measure the ease of travel between two points in space [7]. Foreign scholars have widely adopted this concept and its associated methods to examine the spatial configurations of educational facilities. This research covers a range of topics, such as the partitioning and planning of school districts [8], traffic cost analyses for educational facility accessibility [9,10], analyses of primary school clustering patterns in spatial layouts [11], comparisons of primary school accessibility across different cities [12], and the economic and social impacts resulting from changes in school accessibility [13]. Since the 21st century, domestic scholars have endeavored to integrate spatial accessibility into the analysis of educational facilities, particularly in their distribution and balance across various educational institutions, such as kindergartens, primary schools, middle schools, and high schools.

The common methods of spatial accessibility include the distance method, the cumulative opportunity method [14], the two-step floating catchment area (2SFCA) method and its improved forms [15,16], and the potential model and its improved forms [17,18]. Among them, the distance method solely takes into account distance factors and does not consider other factors, such as the size of supply and demand points. This makes it challenging to visually analyze the supply and demand situation of primary school facilities. The cumulative opportunity method expresses the accessibility of school facilities in terms of cumulative opportunity, taking into account factors, such as the transportation system and land use. However, it does not consider the impact of distance decay. The potential model adopts a decay function that considers both supply-side and distance factors but does not consider demand-side factors. The conventional 2SFCA accounts for multiple factors, such as supply and demand sides, distance, and more. However, its inefficiency in terms of repeated calculations limits its ability to comprehensively consider multiple modes of transportation behavior. Furthermore, coupled with the uncertainty of distance thresholds, there can be variations in the results obtained in practical research.

According to existing research, there are two key areas that require improvement. Firstly, traditional education facility planning predominantly relies on total and per capita indicators, overlooking crucial factors, such as actual population demand and the spatial distribution of facilities [19]. There is a lack of quantitative assessments of the "spatial matching degree" between the spatial distribution of education facilities and the distribution of a residential population [20]. The second area that requires improvement is the selection of the research scale, which often faces challenges regarding scope and precision. For instance, research areas may be too narrowly defined, leading to insufficient spatial precision. Numerous studies have focused on individual streets, regions, or schools as their research domains. As such, they are limited in their ability to assist in the allocation of educational facilities on a wider scale. Additionally, in terms of spatial precision, existing studies often utilize streets and communities as the smallest population scale unit, but this level of precision may not be sufficient and is susceptible to uncertainty [21,22].

In response to the aforementioned issues, to enhance the analysis of the spatial distribution and accessibility of primary school facilities, this study conducted the following experiments: (1) analysis of the distribution of permanent residents and school-age children in Chengdu through population spatialization; (2) analysis of the spatial distribution and balance of primary school facilities in Chengdu through a kernel density analysis and imbalance index analysis; (3) using the multi-traffic model two-step floating catchment area (MM2SFCA) method, the accessibility of primary school facilities in Chengdu was analyzed from the perspective of supply and demand; (4) use of the spatial autocorrelation analysis to verify the results of spatial accessibility of primary schools and to interpret and analyze them.

2. Data Sources and Methods

2.1. Study Area

Chengdu is located in the western part of the Sichuan Basin and on the eastern edge of the Tibetan Plateau. The city has a flat topography and a network of rivers. It also has a well-developed agriculture and rich products. It is an important high-tech industrial base, economic and trade center, and comprehensive transportation hub in southwest China. The administrative area of Chengdu City covers 14,335 km², including 12 municipal districts, 3 counties and 5 county-level cities. This paper, in accordance with the "Chengdu City Urban Master Plan 2011–2020", is divided into three circle structures: the central circle includes Jinniu District, Wuhou District, Jinjiang District, Chenghua District, and Qingyang District; the second circle includes Xindu District, Pidu District, Wenjiang District, Qingbaijiang District, Longquanyi District, and Shuangliu District [18]; and the third circle includes Dujiangyan City, Pengzhou City, Jintang County, Jianyang City, Pujiang County, Xinjin County, Qionglai City, Dayi County, and Chongzhou City, as shown in Figure 1.



Figure 1. Geography, topography, distribution of districts and counties, and distribution of primary schools in Chengdu, Sichuan Province.

2.2. Data Sources

The study data include land-use data, night lighting data, digital elevation model data, road network data, point of interest data, demographic data, and primary school facility

data, all data collection years are 2020. The night light data were obtained from the extended NPP/VIIRS time series data product published in Document 33 with a spatial resolution of 500 m. The digital elevation model data was downloaded from the Geospatial Data Cloud with a resolution of 30 m. The road network data was sourced from OpenStreetMap and was divided into highways, urban arterials, urban secondary roads, feeder roads, and secondary roads. The point of interest data were obtained from the open application programming interface (API) provided by Amap (https://ditu.amap.com/ (accessed on 19 December 2022)), and a total of 768,332 records were crawled by the software. The population data were obtained from the Seventh and Sixth Population Census Reports of Chengdu City and its districts and counties. The data include the number of permanent residents in Chengdu City from 2010 to 2020, the age structure, the size of the permanent population in each district and county and street, and the size of the population at birth from 2008 to 2014. The data on primary schools were collected from various sources, including the school information section of the Chengdu Municipal Education Bureau's website, the websites of each district and county education bureau, and the official websites of schools. A total of 886 primary school sites were identified, which is consistent with the number of primary schools announced by the Chengdu Municipal Education Bureau.

3. Analytical Methods

3.1. Spatialization of Population

The random forest is an extension of the Bagging method for ensemble learning. It combines multiple decision trees into a basic learner by introducing randomization rules. By combining several weak classifiers, the final result can be voted on or averaged, improving the accuracy and generalization performance of the model. This approach achieves good results in the final effect.

The correlation between population density and each variable factor was calculated using SPSS 22.0 software, and the factor with a strong correlation with the population density ($r \ge 0.6$) was determined as an independent variable after a comparative analysis. Through factor selection, factors, such as the Point of Interest kernel density value, mean value of night light brightness, land-use index, road network density, and elevation, were identified as independent variables, with the street population density as dependent variables [23], and a random forest model was constructed to simulate the spatial distribution of the population on a 250 m grid in Chengdu [24–26]. The random forest model was run on the R language platform with the following parameter settings: ntree = 500, mtry = 3, and other default settings. The calculation is shown in Equation (1):

$$Rpop'_{ji} = Real_j \times \frac{Rpop_{ji}}{Rredict_j}$$
(1)

where $Rpop'_{ji}$ is the estimated population in grid *i* of the *j*th district and county after total control; $Rpop_{ji}$ is the estimated population in grid *i* of the *j* district and county; $Real_j$ is the actual population in the *j*th district and county; $Rredict_j$ is the total estimated population in the *j* district and county.

To judge the accuracy of the population grid assignment results, 259 streets in Chengdu were divided into a test set and a training set at a 2:8 ratio. When dividing the dataset, 20% of the street population was used as the test set to verify the model's regression accuracy, and the accuracy of the model results was evaluated using the coefficient of determination (R^2) , as shown in Equation (2).

$$R^{2} = 1 - \frac{\sum_{i=1}^{n} (Pop_{i} - Pop'_{i})^{2}}{\sum_{i=1}^{n} (Pop'_{i} - \overline{Pop})^{2}}$$
(2)

where Pop_i is the actual population value of the street, Pop'_i is the estimated population value of the street, and \overline{Pop} is the average value of the actual population of all streets.

3.2. Kernel Density Estimation

Kernel density estimation [27,28] does not assume anything about the distribution of the sample data, and it studies the prediction method of the data distribution characteristics; let the sample data $x_1, x_2, ..., x_n$ be the collected sample data with independent identical distribution [29], and then, the kernel density function F(x) at any arbitrary point x is estimated as shown in Equation (3).

$$F(x) = \frac{1}{nh} \sum_{i=1}^{n} K(\frac{x - x_i}{h})$$
(3)

where F(x) is the kernel density function; *h* is the distance decay threshold, *n* is the number of point elements within the search distance, *K* is the spatial weight function, and $x - x_i$ is the distance from point *x* to point x_i .

3.3. Imbalance Index Method

The imbalance index method is used to measure the differences in the spatial distribution of primary schools in different districts and counties [30], and in this paper, the concentration index model of the Lorenz curve is chosen to analyze the degree of balance in the distribution of primary schools, as shown in Equation (4).

$$S = \frac{\left[\sum_{i=1}^{n} Y_i - 50(n+1)\right]}{100n - 50(n+1)} \tag{4}$$

where *S* is the imbalance index, *n* is the number of study areas, and Y_i is the *i*th cumulative percentage of the number of primary schools in the study area as a proportion of the total number of primary schools in the city, ranked from largest to smallest. If 0 < S < 1, it means that primary schools are unevenly distributed in the study area; if S = 0, it means a balanced distribution; and if S = 1, it means that primary school are concentrated in a particular study area.

3.4. The MM2SFCA Method

The traditional 2SFCA method utilizes a predetermined travel distance or time threshold as the search radius and searches by moving twice and compares the number of resources or facilities that residents can access within the threshold; the higher the value, the better the accessibility [31,32]. In this study, the road data network of Chengdu city is used to calculate the travel cost, and the combination of multiple transportation modes is added to the traditional 2SFCA method. This approach is more aligned with the transportation modes commonly utilized by residents for travelling and schooling at this stage. Specifically, walking is preferred for close schooling, followed by the use of electric motorbikes, and some residents opt for cars for the long-distance transportation of children.

The selection of a reasonable critical value is an important basis for the quality of the accessibility analysis. According to the Urban Residential Area Planning and Design Standards, the service radius of a primary school should not exceed 800 m. However, in practice, over 80% of the primary school facilities in the second and third circles were not accessible, except for the five urban areas in the center of Chengdu, which was not in line with the actual situation. To address this situation, this study used buffer analysis to determine the appropriate service radius; each primary school was taken as the center, and a buffer zone was established. Through a comparison, it is found that when the buffer radius is 5000 m, the buffer coverage can reach the degree of 98%, so this study selected 5000 m as the search radius. Based on the impact of traffic lights on travel paths and the transportation modes used by children for commuting, it was established that the

maximum distance for children to walk to school is 500 m, the distance range for choosing electric motorcycles as a mode of transportation to school spans from 500 m to 2500 m, while the distance range for opting for cars is between 2500 m and 5000 m.

The MM2SFCA method is divided into two steps: in the first step, the supply/demand ratio R_j is calculated for the demand point, settlement I, within the search range of the supply point school j under different transport modes M_n .

The priority order of transportation modes is walking (M_1) , electric motorcycles (M_2) , car (M_3) . To avoid accumulating and repeatedly calculating the population of residential areas under different traffic modes, the population of residential areas covered by the previous preferred traffic mode needs to be deducted when calculating the population of residential areas under the next preferred traffic mode; see Equations (5) and (6).

$$R_{j} = \frac{S_{j}}{\sum_{i \in \{dij(M1) \le do(M1)\}} Pi(M1)Gij(M1)g(dij(M1)) + \sum_{i \in \{dij(M2) \le do(M2)\}} Pi(M2)Gij(M2)g(dij(M2)) + \dots + \sum_{i \in \{dij(Mn) \le do(Mn)\}} Pi(Mn)Gij(Mn)g(dij(Mn))}$$
(5)

$$P'_{i}(M_{2}) = P'_{i}(M_{2}) - P'_{i}(M_{1}), P'_{i}(M_{n}) = P_{i}(M_{n}) - Pi(M_{n-1})$$
(6)

where $P_i(M_n)$ denotes the number of the demand population of settlement *i* within the search radius in the M_n traffic pattern, $P'_i(M_n)$ is the number of the population of all demand points in the M_n traffic pattern minus the number of demand points within the search radius in the priority M_{n-1} traffic pattern, $G_{ij}(M_n)$ is the weight of the selection of settlement *i* to school *j* in the M_i traffic pattern, and $g(d_{ij}(M_n))$ is the distance attenuation function (Equation (7)).

$$g(d_{ij}) == \frac{e^{-\frac{1}{2} \times \left(\frac{dij}{do}\right)} - e^{-\frac{1}{2}}}{2 - e^{-\frac{1}{2}}}, d_{ij} \le do$$
(7)

In the second step, following the same calculation, the supply–demand ratio R_n of school *j* within the search radius of each settlement *i* under the M_n traffic pattern is calculated. Then, the supply/demand ratio of each school within the search area is scaled and accumulated to ultimately obtain the accessibility A_i of each settlement *i* (Equation (8)).

$$A_{\mathbf{i}} = \sum_{i \in \{dij(M1) \le do(M1)\}} Rj(M1)Gij(M1)g(dij(M1)) + \sum_{i \in \{dij(M2) \le do(M2)\}} Rj(M2)Gij(M2)g(dij(M2)) + \dots + \sum_{i \in \{dij(Mn) \le do(Mn)\}} Rj(Mn)Gij(Mn)g(dij(Mn))$$
(8)

3.5. Spatial Autocorrelation Analysis

Spatial autocorrelation analysis is a spatial statistical method used to determine whether a variable exhibits a spatial correlation. If a variable becomes more similar at any time as the measurement distance decreases, this indicates that this variable exhibits a positive spatial correlation and vice versa [33–35].

This study used the local binary Moran spatial autocorrelation method (MSAM) to analyze the clustering relationship between accessibility to primary school facilities and population distribution. MSAM is a measure of the similarity between a spatial unit and its domain. It indicates the degree to which each local unit obeys the global general trend and can be used to represent spatial heterogeneity through LISA diagrams to illustrate how spatial dependence varies with the location. The calculation is shown in Equation (9).

$$I_{ap} = \frac{N \sum_{i=1}^{n} \sum_{j \neq i}^{n} W_{ij} Z_{i}^{a} Z_{j}^{p}}{(N-1) \sum_{i=1}^{n} \sum_{j \neq i}^{n} W_{ij}}$$
(9)

where I_{ap} is the bivariate global autocorrelation index, N is the total number of spatial cells, W_{ij} is the spatial weight matrix, Z_i^a is the normalized value of the accessibility of the *i*th gridded primary school, and Z_j^p is the normalized value of the population size of the *j*th street.

4. Results

4.1. Trends in the Resident Population and the Spatial Distribution of Primary School-Aged Children

Figure 2a illustrates the growth of Chengdu's permanent population from 2010 to 2020, which shows a continuously increasing trend. During the period of 2015–2016, the permanent population increased by 1.26 million people, with a growth rate of 8.6%. During the period of 2019–2020, the permanent population increased by 4.36 million people, with a growth rate of 20.8%. The rest of the years saw slow growth, with the highest growth rate of 350,000 people. According to Figure 2b, the population in all age groups in 2020 exceeded that in 2010. Among them, the group aged 0–14 years increased by more than 1.487 million people in the past 10 years, with the proportion increasing from 9.7% to 13.6%.



Figure 2. Population change from 2010 to 2020. (**a**) Changes in the resident population over the period 2010–2020; (**b**) comparison of the number of resident populations by age group in 2010 and 2020.

Based on the distribution of the permanent population in Chengdu City in 2020 simulated based on the random forest model, the total estimated population at the street (township) level was fitted with the statistical population data of the seventh census, to verify the accuracy of the population spatialization results. Figure 3b shows that the estimated population and the actual population in 2020 had a significant correlation ($R^2 = 0.8693$) with good overall fitting accuracy. Although there was still a gap between the estimated and actual population, the difference was within the acceptable range for this experiment.

Figure 3a shows the distribution of the resident population of Chengdu City. According to the results of the seventh census, Chengdu has a resident population of 20,937,800, of which 1,062,200 are between the ages of 6 and 12, accounting for 5.07% of the resident population, as shown in Figure 3d. The spatial pattern of distribution of primary school-age children in Chengdu was calculated based on the percentage of primary school-age children, as shown in Figure 3c. The concentration of primary school-age children is highest in the central circle of Chengdu, including Jinjiang District, Chenghua District, and Jinniu District, and the second and third circles show a decentralized distribution centered on the city's urban construction centers, such as Shahongba Street in Jianyang City, Kuixingta Street in Dujiangyan City, and the nearby areas of Xindu Street in Xindu District.



Figure 3. Spatialization of the population. (**a**) Distribution of the resident population in Chengdu; (**b**) population fitting; (**c**) distribution of primary school-age children in Chengdu; (**d**) primary school-age population.

4.2. Spatial Distribution of Primary School Facilities

Figure 4a shows the spatial distribution of primary school facilities. From Figure 4b, it can be seen that more than 90% of the total area of Chengdu was in the low-density and lower-density areas, and almost all of them were located in the areas of the second and third circles. The central circle was the concentrated distribution area of primary schools in Chengdu, with more than 80% of the districts in the average density and above areas.



Figure 4. Characteristics and imbalances in the spatial distribution of primary school facilities. (a) Analysis of the spatial distribution of primary school facilities; (b) statistical analysis of spatial distribution results of primary school facilities; (c) analysis of spatial imbalances in primary school facilities.

In order to reflect the extent to which the study primary schools were balanced or unbalanced within the different districts and counties of Chengdu City, the disequilibrium index analysis was used to calculate the disequilibrium index S = 0.257. The Lorenz curve plotted in Figure 4c shows that 50% of the primary schools were distributed in seven districts and counties in the central and eastern parts of Chengdu, including Jintang Country, Jianyang City, Wuhou District, Jinniu District, Shuangliu District, Xindu District, and Longquanyi District, while nine districts and counties in the western part of the city accounted for only 23% of the total.

4.3. Spatial Accessibility of Primary Schools

Figure 5a shows the spatial accessibility of primary school facilities. From Figure 5b, it shows that the accessible area in Chengdu accounts for 49.3% of the total area, the low and less accessible area accounts for 24.2% of the total area, and the generally accessible and above area is 26.2% of the total area. The overall accessibility of the central city was good, and the accessibility decreased from the inside to the outside, with 82.7% of the area being generally accessible and above, and almost no inaccessible area. The second circle of Xindu, Qingbaijiang, and Longquanyi districts was distributed with high accessibility areas, while the centers of other districts and counties had average accessibility areas, and 32.2% of the districts were inaccessible areas. Only 9.1% of the third circle had good accessibility, mostly in district and county centers and inaccessible peripheral areas, such as the right edge of the Longmen Mountain Range on the western edge of Chengdu, the rural areas of Jianyang City, and the Longquanshan Urban Forest Park section of Qingbaijiang District. A total of 56.5% of the area was inaccessible, including the Longmen Mountain Range on the western edge of Chengdu City, the Longquanshan Urban Forest Park on the edge of Longquanyi District, parts of Jianyang City, and the edges of Qionglai City, Pujiang County, Xinjin County, and Shuangliu District.



Figure 5. Primary school spatial accessibility map display and quantitative statistics. (a) Accessibility map of primary schools in Chengdu; (b) statistical analysis of the results of accessibility of primary school facilities.

4.4. Correlation between Population Distribution and Accessibility of Primary Schools

Figure 6a shows the correlation between the population and access to primary school facilities. Based on the calculation results, the global bivariate Moran's I = 0.238, which represents a positive spatial relationship between primary school facilities and population density in Chengdu. Figure 6b shows that the agglomeration area accounted for 39% of the total area of Chengdu, and 27% of the area was in the low-low agglomeration area. It can be seen that 74.3% of the area of the middle circle was in the high-high agglomeration area, 9.8% of the area of the second circle was in the high-high agglomeration area, 4.7% of the

area was in the low-low agglomeration area, and 76.5% was in the insignificant area. In the third circle, 5.5% of the area was in the high-low agglomeration area, 52% of the area was in the low-low agglomeration area and 58.1% of the area was in the insignificant area.



Figure 6. Map presentation and quantitative statistics based on the correlation between population distribution and the accessibility of educational facilities in Chengdu. (**a**) Relevance map of primary schools in Chengdu; (**b**) statistical analysis of autocorrelation analysis in Chengdu primary schools.

5. Discussion

5.1. Population Change with a "One Point, Many Cores" Pattern

The year 2010 was the sixth population census of Chengdu, and 2020 was the seventh population census of Chengdu. Analyzing the population changes over the 10-year period and comparing the age structure, the total population of Chengdu was large, with a total resident population of 20,937,800 in 2020, accounting for 25.02 per cent of Sichuan Province, an increase of 6,890,200 compared with 2010, a growth rate of 49.04 per cent, and a huge increase in the 10-year period.

In terms of the age composition of the population, the data from the Seventh Population Census show that the structure of the population has changed in an elongated 'U' shape, i.e., the proportion of the population in the younger and older age groups has increased, and the proportion of the population in the middle working-age group has decreased. Census data show that the number of children aged 0–14 increased by 1,487,000 compared to in 2010, an increase of 3.9 percentage points, indicating that the number of children of primary school age has continued to grow significantly in recent years and will continue to do so in the coming years.

From the perspective of spatial distribution, the current population distribution in Chengdu City shows a trend of centralized and differentiated development [36]. The population decreases from the center to the periphery. The overall distribution of primary school-age children shows a decentralized pattern of "one point and multiple nuclei", where "one point" was the central circle composed of Chengdu's earliest urban areas, including Jinjiang, Chenghua, Wuhou, Qingyang, and Jinniu districts, which have a long history of development, strong economic strength, and well-developed transportation and various types of infrastructure, attracting a large number of foreigners to move in and settle, forming a high degree of aggregation of primary school-age children in the central urban area; here, "Multi-core" was the central urban areas of the second and third circles, which are generally located in the economically developed central urban areas, which have proposed preferential policies to attract enterprises to invest in the development of the region, promote the development of the economy, and form the characteristics of a single point of primary school-age children agglomeration. Among them, most of the urban areas in the third circle were transferred from the Chengdu Municipality in recent years. The distribution of primary school-age children is low due to various factors, such as the

topography, economy, and transportation. They are mainly concentrated in the lower part of the mountain range in the Chengdu Plain area.

At the same time, we have found that the distribution of primary school facilities in Chengdu was similar to the distribution of the population of primary school-age children, with the characteristics decreasing from the center to the outside, with the central circle having the highest density and the second and third circles having gradually decreasing densities. The central circle has a rich developmental history, high population density, and comprehensive infrastructure. The areas with higher density in the second and third circles are mostly concentrated in the urban center and are more complete due to the concentration of the population [37].

5.2. Spatial Accessibility of Primary Schools Is Closely Linked to the Distribution of School-Age Children by Population

Overall, the accessibility of Chengdu's central city and the central cities of its districts and counties was good. However, there was still significant variability across regions and circles.

Highly accessible and relatively highly accessible areas were mainly distributed in the city center and the district and county centers of the second and third circles. These areas have better economic development, a dense population distribution, and sufficient primary education resources, so they have higher accessibility. The highly accessible areas are also found in the right-hand edge areas of the Longmen Mountain in the western edge of Chengdu, the rural areas of Jianyang City, and the Longquanyi section of the Qingbaijiang urban forest park. The analysis combined the accessibility results with the correlation of the population. The findings indicate that these areas have a remote geographical location, sparse population distribution, and a larger service range of primary schools compared to the city center. However, due to the impact of transportation and road networks and the study's set 5000 m search distance, fewer people are eligible within the primary school service range, resulting in higher accessibility. This created a high-low clustering situation, which highlights a mismatch between the distribution of primary school facilities and the population.

The low-high clustering areas represented regions with lower accessibility to primary schools but high population densities, mainly located in the Pidu, Wenjiang, Shuangliu, and Longquanyi districts. These areas were located in the second circle of Chengdu, which had good transportation and was in a rapid development stage. The population of the five central urban districts was oversaturated, and an increasing number of residents were choosing to live in the second circle. With a large influx of population, the original primary school resources in the second circle were inadequate to support the impact of rapid population growth, resulting in a low-high clustering situation with low accessibility but a high population density.

The low-low clusters are widely distributed in the Longmen Mountain area in the western part of Chengdu City [38], as well as in the rural areas of Pujiang County, the border area between Jianyang City and Ziyang City, and the intersection of Longquanyi District, Qingbaijiang District, and Jintang County. Considering the higher altitude of the western area and the simultaneous existence of several nature reserves and scenic spots, this results in a lower distribution of primary school facilities and population in the western part of the area. The border and peripheral areas of Pujiang County and Jianyang City are affected by the geological environment, the influence of transportation and road networks, and the lower distribution of the population, which resulted in a lower accessibility of primary school facilities [39].

5.3. Uncertainties and Limitations

This paper simulated the population distribution of Chengdu city on a 250 m grid, used kernel density estimation and an imbalance index to analyze the spatial distribution characteristics and balance of primary school facilities in Chengdu city, measured the

accessibility of primary school facilities in Chengdu city, and finally analyzed the correlation between the spatial distribution of primary school-age children and the accessibility of primary school facilities by using Moran's spatial autocorrelation variable [20]. The presented methodology can serve as a reference for evaluating the spatial equity of other public service facilities in cities. However, this paper has some limitations. Firstly, this study combined multi-source data to simulate the distribution of primary school-age children in a 250 m grid in Chengdu, and although the accuracy was improved compared to most studies, there was still room for further improvement. Secondly, this study did not distinguish well between quality education and general education in primary schools, and this needs further improvements.

Therefore, future studies should evaluate the spatial distribution and accessibility of primary school facilities in a more practical and refined manner, taking into account the actual schooling situation and the needs of different areas and residents. This will provide more accurate suggestions for the allocation of primary school facilities. Additionally, it is important to study the causes and effects of educational resource equity [16].

6. Conclusions

The significance of education in social development is becoming increasingly prominent. Vigorously promoting educational equity and promoting the sustainable development of education are conducive to the sustained, stable, and healthy development of the national economy, improving people's living standards and quality, promoting social equity and justice, and reducing poverty and inequality.

We used population spatialization to analyze the distribution of the resident population and the population of primary school-age children in Chengdu, measure the balance of primary school facilities, and finally analyze the correlation between the primary school-age children and accessibility by combining spatial autocorrelation [40]. The population of Chengdu has been growing rapidly in the most recent ten years, and the number of primary school-age children was also increasing. The overall distribution of primary school-age children in Chengdu shows a decentralized pattern of "one point, many nuclei", with the population decreasing from the center to the periphery, which mainly depends on the economic strength and the degree of development of transportation and various types of infrastructure, which can attract a large number of foreigners to move in and settle down. The distribution of primary school facilities was similar to the distribution of the population, mainly built around the population; with an imbalance index of 0.257, there was a certain imbalance, which was mainly represented by a larger number of primary school facilities in the east-central part of the city and a smaller number in the west.

Furthermore, the central area of Chengdu boasts excellent accessibility and a high population density. The accessibility and population of the second ring were mainly concentrated in the urban development center. However, due to the rapid growth of population and the lack of a timely increase in educational resources, the accessibility and population of the second ring also presents a low-high clustering situation. The third circle presents a low accessibility and low population situation as a whole, but due to the influence of transportation networks and population spatial gridlization, some grid populations were extremely low, resulting in a high supply–demand ratio calculated within the search radius, showing a high accessibility and low population relationship in some marginal areas [38].

This study attempted to analyze the spatial distribution and accessibility of primary school facilities in Chengdu from a holistic perspective, highlighting the imbalance and accessibility of primary school facilities in Chengdu, as well as the correlation between accessibility and the population of primary school-age children, in order to provide ideas and suggestions for the allocation of relevant educational facilities.

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