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A Study on the Current Situation of Public Service Facilities' Layout from the Perspective of 15-Minute Communities—Taking Chengdu of Sichuan Province as an Example

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Abstract: With the rapid expansion of cities, the construction of 15-minute communities has become an important way to improve the urban living environment and enhance the quality of life of residents. In this study, based on the perspective of a 15-minute community in Chengdu, the current situation of the spatial layout in the 12 main urban districts of 15,941 public service facility points is studied. Additionally, the matching relationship between the supply and demand of five major categories (19 subcategories) of public service facilities and the population is assessed by using the kernel density analysis method, the Gaussian two-step floating catchment area method, the hierarchical analysis method and the bivariate spatial autocorrelation. Finally, suggestions for the optimization of basic service facilities are made in the light of the current development situation in Chengdu. The results show that (1) there is a large spatial heterogeneity in the distribution and accessibility of public service facilities in the study area; (2) there is a mismatch between the supply and demand of public service facilities and the population in Chengdu; and (3) in order to further optimize the allocation of public service facilities, it is necessary to focus first on areas where demand exceeds supply. This study built a framework for assessing the current status of spatial distribution of public service facilities, which measures the 15-minute accessibility of basic public service facilities in a more comprehensive way and bridges the gap of previous single-type studies, which make it difficult to make comprehensive optimization recommendations directly. Meanwhile, the bivariate spatial autocorrelation reveals the areas of mismatch between supply and demand more accurately, and more clearly shows the areas that need to be focused on for optimization by policy makers.

Keywords: 15-minute communities; public service facilities; two-step floating catchment area method; accessibility measurement; Chengdu

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Citation: Sun, Y.; Luo, S. A Study on the Current Situation of Public Service Facilities' Layout from the Perspective of 15-Minute Communities—Taking Chengdu of Sichuan Province as an Example. *Land* **2024**, *13*, 1110. https://doi.org/10.3390/land13071110

Academic Editors: Guangyu Wang, Zhaowu Yu, Jiang Liu, Xin-Chen Hong, Baojie He and Xiong Yao

Received: 25 June 2024
Revised: 12 July 2024
Accepted: 17 July 2024
Published: 22 July 2024

1. Introduction

Rapid urban expansion has resulted in the need for people to commute long distances for a wide range of urban services. However, this is not conducive to sustainable urban development [1]. In recent years, researchers have argued that urban planning should enhance the quality of life by enabling residents to access a wide range of urban services needed for daily life through short-distance trips [2]. As early as 1929, Clarence A. Perry introduced the concept of the "neighborhood unit" [3]. Similarly, "x-minute cities" are cities where residents can access most of their needs within a short walk or bike ride from their homes [2]. The "15-minute city" is one of the most successful examples of this. In 2016, Carlos Moreno introduced the concept of the 15-minute city in the construction of a framework to fight against greenhouse gas emissions [4]; in 2019, the various containment and control measures taken in response to the outbreak of the COVID-19 brought attention to this concept [5,6]. The 15-minute city is now being studied and practiced in many cities around the world, including Paris, Tempe and Melbourne [1,7].

Amir Reza Khavarian-Garmsir's study reviews books and publications related to the 15-minute city and proposes that the realization of the 15-minute city relies on the seven principles of density, diversity, and proximity. The 15-minute city is economically and environmentally sustainable through humanistic design and an urban scale that allows people equal access to the services in the city [8]. However, the current implementation of this concept suffers from the absence of a generalized construction methodology and the neglect of the different travel behaviors and needs of various groups of people [9]. Among the practice-specific studies, Beniamino Murgante et al. (2024) constructed a framework to assess the proximity, density, and diversity of the spatial structure of urban areas in Italy based on the 15-minute city concept [10]; Kate Hosford et al. (2022) calculated the 15-minute accessibility to Vancouver's grocery stores on foot versus by bicycle using the cumulative opportunity metric [11]. Additionally, Beatrice Olivari et al. (2023) proposed a new methodology for the calculation of the proximity index and practiced it in Ferrara, Italy. The study argues for the global replicability of the index calculation in terms of the global availability of research data, providing a generalized methodology for research in other regions [2].

Currently, China's urbanization process is advancing rapidly and is in the middle to late stage of urbanization [12]. The focus of urban development has shifted from high-speed development to high-quality development [13]. Therefore, it has become an important way to improve the urban living environment and enhance the quality of life of the residents by perfecting the planning of the community living area centered on the residents' daily activity space [14]. In 2016, Shanghai took the lead in proposing the 15-minute Community Living Circle Planning Guidelines (Trial) [15], and in 2023, through the integration and implementation of the Technical Guidelines for Community Living Circle Planning [16], it proposed construction guidelines for districts, departments, and streets and towns at the operational level. At the same time, Beijing, Nanjing, Wuhan and other major cities have also put forward 15-minute living area planning guidelines and started construction work [17].

Public service facilities are the basis for meeting the needs of residents in their daily lives. The urban functions in the 15-minute living circle concept include five major categories: living, healthcare, education, transportation, and entertainment [4]. Living service facilities refer to locations that meet the necessary needs of people in their daily lives, such as shopping, dining, and banking. As such, a study proposes that the pedestrian accessibility of these daily living services is a key strategy for realizing the 15-minute city [9], and its realization can reduce the wasted travel time of residents and reduce carbon emissions. Healthcare facilities include general hospitals, clinics, emergency centers, and other locations that meet the health needs of the population; in a 15-minute living circle, these facilities allow vulnerable groups such as the elderly and children to receive medical assistance more quickly [18]. Educational facilities are places that provide education for children of different ages, including kindergartens, elementary school and secondary schools. Keeping educational facilities within a 15-minute walking distance of residential areas makes it easier for parents to pick up and drop off their children, and provides a safer and more convenient environment for children to travel to and from school [19]. Public transportation facilities refer to subway stations, bus stops and other public transportation sites, which can reduce residents' reliance on private cars and solve the "last kilometer" problem of connecting settlements and destinations [20]. Moreover, a study from Australia showed that transportation costs for households living in car-dependent travel patches were twice as high as those living in pedestrian-friendly areas [21]. This suggests that active traveling has a role to play in saving residents' expenditures on gasoline, auto repairs, and parking fees. Entertainment facilities refer to places that meet the recreational needs of residents, including plazas, parks and green spaces, sports facilities, etc., which can enrich the lives of residents, increase the sense of urban identity among residents, and create opportunities for leisure and relaxation [22,23]. These five types of public service facilities provide residents with the necessary basic functions for daily life and are not replaceable with each other [24]. Therefore, the spatial configuration and high 15-minute accessibility of public service facilities are the key to building 15-minute communities (living areas).

Moreover, theories of environmental equity and distributive justice require that residents have equal access to public service facilities [25]. The United Nations Sustainable Development Goals call for livelihood security for all, especially vulnerable groups such as women, children and the elderly. However, there are still problems of duplicated allocation and inefficient services in the spatial allocation of public service facilities [24].

Existing research on amenity allocation in the living area focuses on equity and efficiency, using a variety of methods to measure the accessibility of public service amenities. Computational methods for accessibility include network analysis [26], minimum distance method [27], cumulative chance measure [28], gravity modeling [29], and two-step floating catchment area method (2SFCA) [30]. Some of these methods measure accessibility from the demand side, such as the minimum distance method, while methods such as network analysis measure accessibility from the supply side. The 2SFCA, on the other hand, incorporates both the supply side and the demand side in its estimation, and therefore provides a more comprehensive picture of accessibility [31]. In 2000, Radke proposed the two-step floating catchment area method [32], but the traditional 2SFCA is greatly affected by the threshold of travel time or distance [33], so subsequent studies proposed various improved methods [34,35]. For example, Luo and Qi [36] introduced a Gaussian function as the distance decay function within the search radius on the basis of the traditional 2SFCA, and proposed the Gaussian two-step floating catchment area (Ga2SFCA). Some scholars have included multiple modes of transportation, including walking, bicycling, and automobiles, in accessibility considerations to bring them more in line with actual travel situations [37]. Thus, the improved 2SFCA is also increasingly used to measure the accessibility and spatial equity of public service facilities. For example, Langford used the improved 2SFCA to calculate the accessibility of primary health care facilities based on public transportation [38], and Zhang used the improved 2SFCA based on the 15-minute city perspective to reveal the imbalance in the accessibility of parks in Guangzhou [24].

While the above studies reveal that there are inequalities in the accessibility of various public service facilities, there are still certain research gaps. First, previous studies have focused more on the accessibility of single types of public service facilities, such as healthcare [39] and parks or green spaces [25]. However, there are fewer studies on the comprehensive accessibility of public service facilities provided within the living area, as it is difficult to propose optimization recommendations comprehensively from the results of a single type of research. Second, fewer studies have measured the accessibility of the above public service facilities based on the perspective of the 15-minute living circle. Although the construction of 15-minute living circles has begun in major cities such as Beijing and Shanghai, fewer studies have made efforts to assess the current status of the accessibility of public service facilities in the 15-minute living circles, which is important for refining and improving the current construction status. Finally, whether the supply and demand of public service facilities matches the population distribution is another important indicator to be considered for 15-minute communities. Spatial autocorrelation can reveal the relationship between the supply and demand of public service facility resources and the population, which is one of the key means to more accurately identify the inadequacy of public service facilities and propose the optimization of facility allocation.

In order to fill the above research gaps, this study aims to analyze the 15-minute comprehensive accessibility and the demand relationship of five major types of public service facilities in Chengdu. In detail, this study conducts a status quo study on the spatial allocation of public service facilities in Chengdu through the Ga2SFCA method, to understand which communities in the city are still unequal in terms of 15-minute accessibility, and to measure the match between population and resources by Moran's index. Finally, to propose optimization suggestions for 15-minute community planning, which will serve as a reference for policy formulation. Figure 1 shows the framework of the study.

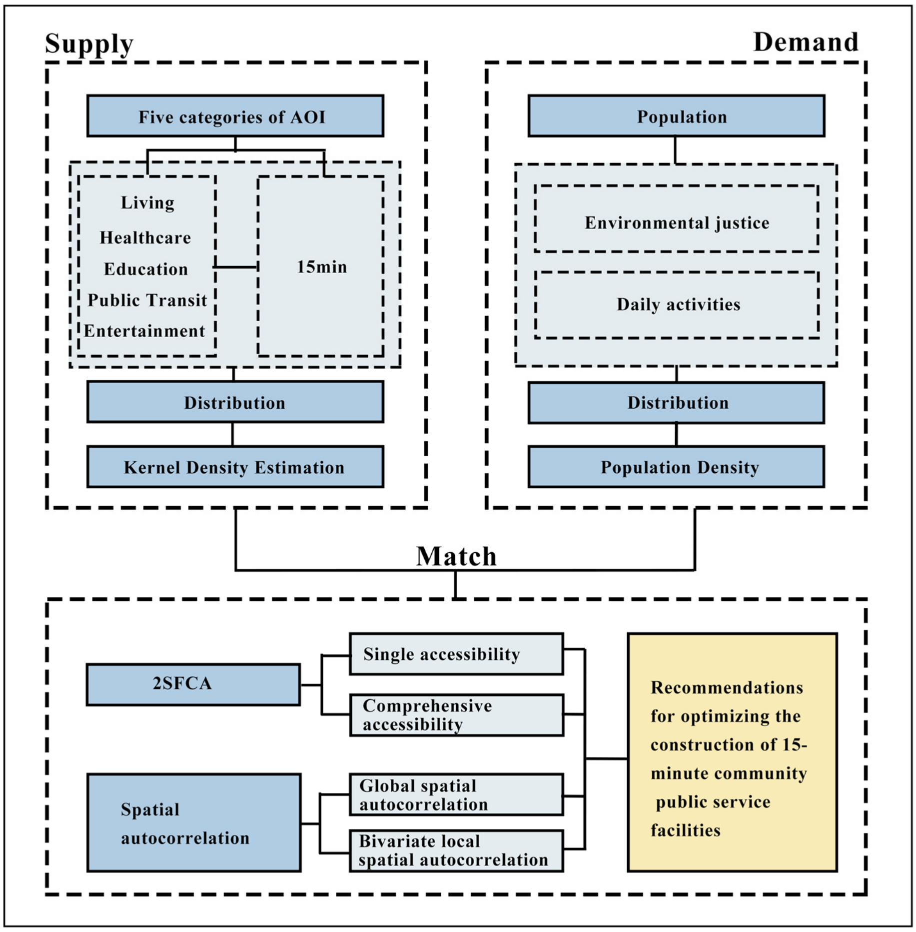

Figure 1. Analytical framework of the study.

2. Materials and Methods

2.1. Study Area

Chengdu (Figure 2) is located at 102°54′~104°53′ east longitude and 30°05′~31°26′ north latitude and is the capital of Sichuan Province and the national central city, with a total area of 14,335 square kilometers. At the end of 2023, the resident population of Chengdu City was 21.403 million, the urbanization rate of the resident population was 80.5%, and the gross domestic product (GDP) was CNY 2207.47 billion [40,41]. This study focuses on 12 municipal districts (including 2 economic functional zones) in Chengdu, including the Jinjiang and Qingyang districts, totaling 4062.6 square kilometers (2021).

The reasons for choosing Chengdu as the study area are as follows: (1) Like Beijing, Shanghai and other cities, Chengdu is one of the first 30 urban quarter-hour convenience living circle pilot cities in China. However, at present, the Chengdu government has only conducted pilot construction for individual communities and has not yet formally proposed detailed guidelines for the 15-minute living circles, as in Shanghai, which suggests that some prior research is needed to provide basic data to support the subsequent policy formulation and implementation. (2) Chengdu's "14th Five-Year Plan" is closely aligned with the construction of a 15-minute public service circle. In the 13th Five-Year Plan, Chengdu has basically formed a 15-minute public service circle, with 5730 new projects in education, healthcare, culture and sports, a total construction volume nearly seven times higher than that in the same period in the 12th Five-Year Plan [42]. In the 14th Five-Year Plan, Chengdu will combine the construction of complete residential communities to make up for the shortcomings of basic public service facilities and coordinate the construction of public service facilities such as basic education, pension, sports and farmers' markets.

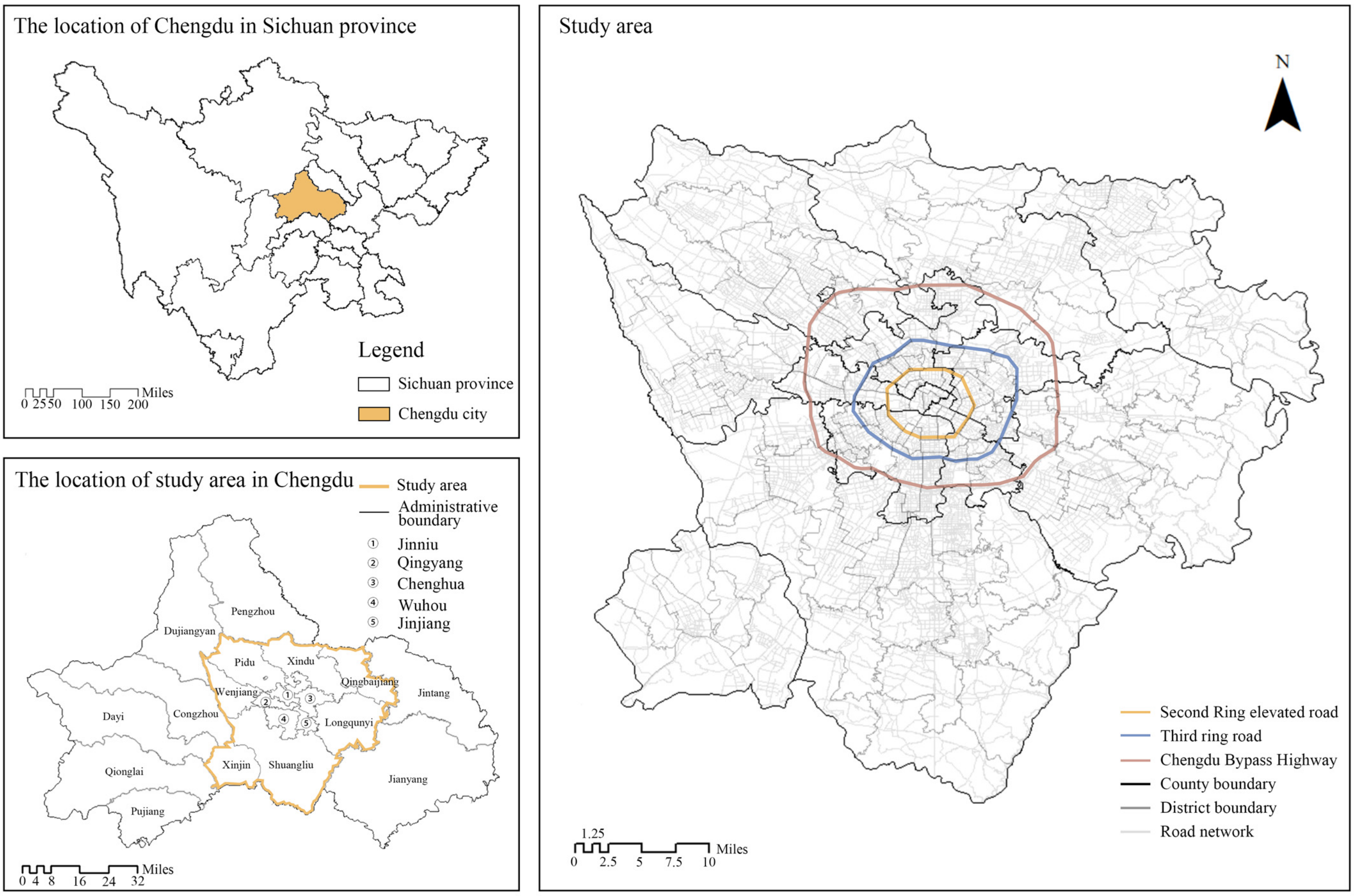

Figure 2. Location of the study area.

2.2. Data Acquisition and Processing

The research data in this paper mainly consist of 2024 AOI (Area of Interest) data, Open Street Map data, and community population data for 12 municipal facilities in Chengdu.

Facility names, categories, areas, coordinate information, and other details for education, healthcare, recreation, and lifestyle services are included in the AOI data, which were obtained from the Baidu Open Platform (https://lbsyun.baidu.com/, accessed on 24 February 2024) in February 2024, ensuring that the data are up to date. Due to the lack of AOI data for public transportation stops, POI (Point of Interest) was used instead [43], and the data were obtained by the real-time bus query program (https://www.8684.cn/, accessed on 15 May 2024). The public service facilities (here after PSF) for the entire study area consisted of 5 major categories and 19 subcategories, as shown in Table 1, totaling 15,941 pieces of data. Open Street Map (www.openstreetmap.org, accessed on 21 March 2024) was used to obtain road network data, which contained details such as road category, road length, and coordinate location. Population data were obtained from WorldPOP (https://www.worldpop.org/, accessed on 30 March 2024) with 100 m $\times$ 100 m precision population raster data in 2020. Since China's population census is conducted every five years, the most recent data available are from the Seventh Census (street level, often referred to as township level in China) for the year 2020. In addition, WorldPOP's population raster data are projections, so they need to be corrected with the Seventh Census population data at the street level, and then aggregated into community-level population information. The zoning data of Chengdu townships and communities were obtained from the National Geographic Information Resource Catalog Service System and the National Condition Monitoring Platform, respectively, and then corrected to make them more consistent with the current situation.

Table 1. Description of the five AOI categories.

AOI Category	AOI Sub-Category Description
Living	Markets, Banks, Restaurants, Convenience Store, Department Stores
Healthcare	General Hospitals, Specialized Hospitals, Emergency Center, Community Hospitals
Education	Kindergartens, Primary Schools, Secondary Schools
Public Transit	Bus Stops, Metro Stations
Entertainment	Parks, Public Squares, Shopping Center, Art Galleries, Gyms

2.3. Research Methods

2.3.1. Kernel Density Analysis

Kernel density analysis is a commonly used method to reflect the distribution density of point data within a certain range [44], which can be used to describe the layout of spatial point data. The formula for its calculation is as in Equation (1) [45].

$$f = \frac{1}{nh}\Sigma_{i=1}^{n} k(s,h) \tag{1}$$

where $f(x)$ is the probability density estimate at point x, h ($h > 0$) is the bandwidth, n is the number of observations, s is the distance between observation x and the ith observation X_i, and $k(s,h)$ is the kernel function in the form shown in Equation (2).

$$k(s,h) = \frac{1}{\sqrt{2\pi h}}\exp\left(-\frac{s^2}{2h^2}\right) \tag{2}$$

This paper utilizes the kernel density analysis tool of ArcGIS 10.8.1 to analyze the PSF data.

2.3.2. Gaussian Two-Step Moving Search Method

The results of spatial accessibility calculations can be used to evaluate the equity of the spatial layout of urban public service facilities. In this paper, Ga2SFCA [36] is used to calculate the 15-minute accessibility of locations related to living services, healthcare, education, entertainment and public transportation.

The specific steps are as follows:

Step 1: For each supply point j, search the demand quantity P_k for all demand points k within the search radius d_0 of j. Weight the demand quantity using Gaussian distance decay function and sum the weighted demand quantity to calculate the supply–demand ratio R_j. Step 1 is realized according to Equation (3).

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\leq d_0\}} G\left(d_{ij}\right) P_k} \tag{3}$$

where R_j is the supply–demand ratio for each supply point j, S_j is the scale of supply at the supply point, expressed by the size of the facility (the scale of supply at public transportation stations is expressed by the coverage of stations in each community), and P_k is the scale of demand at the demand point i, expressed by the size of the population in each community. d_{kj} is the road network distance from the center of mass of the supply point j to the center of mass of the demand point i. d_0 is the search radius, which is set to 1080 m (the walking speed of an adult is set to 1.2 m/s, and the walking time is 15 min). $G\left(d_{ij}\right)$ is the Gaussian distance decay function, which takes the specific form of Equation (4).

$$G\left(d_{ij}\right) = \begin{cases} \dfrac{^{-\frac{1}{2}\times\left(\frac{ij}{d_0}\right)^2} - ^{-\frac{1}{2}}}{1 - ^{-\frac{1}{2}}}, \left(d_{ij} \leq d_0\right) \\ 0, \left(d_{ij} > d_0\right) \end{cases} \tag{4}$$

Step 2: For each demand point i, establish a search domain with a search radius of d_0, and sum the supply–demand ratios R_j of supply points j within the domain weighted by a Gaussian distance decay function to obtain the reachability A_i of each demand point i. Step 2 is realized according to Equation (5).

$$A_i = \sum_{j \in \{d_{kj} \leq d_0\}} R_j \cdot G(d_{ij}) = \sum_{j \in \{d_{k_j} \leq d_0\}} \frac{s_j}{\sum_{k \in \{d_{kj} \leq 0\}} P_k \cdot \mathrm{G}\left(_{i_j}\right)} \tag{5}$$

Furthermore, in order to have a comprehensive understanding of the accessibility of public service facilities, this paper will calculate the comprehensive accessibility index of five major categories of public service facilities. Since the importance of each type of public service facility may be different in the process of 15-minute living circle construction, the same analytic hierarchy process (AHP) is executed as in the previous study by consulting relevant experts to determine the weights [18]. Specifically, the first author consulted 18 experts in architecture, town and country planning, and landscape architecture at his university for scoring (all of whom are engaged in research and practice related to urban community planning and design), and subsequently weighted the accessibility of the various types of facilities. The final results of the weighting are shown in the Table 2. And then, the accessibility results for each type of facility were normalized using the maximum value method and weighted and summed separately, i.e., the 15-minute comprehensive accessibility for each community; then, the 15-minute composite accessibility for each street unit was obtained by averaging the results.

Table 2. Public service facilities weights result by AHP.

AOI Categories	Living	Healthcare	Education	Public Transit	Entertainment
Weight	0.1558	0.1330	0.1637	0.2645	0.2830

2.3.3. Bivariate Spatial Autocorrelation

Bivariate global spatial autocorrelation describes the correlation between the spatial lags of one variable and the other, and the result can be expressed by Moran's index, which takes values in the range [−1,1], where positive values indicate that the variables are spatially positively correlated and vice versa, and larger absolute values indicate stronger spatial correlation. Local bivariate spatial autocorrelation then further shows the relationship between the two variables in the object of study [24]. The specific calculations described above were realized using GeoDa software (version 1.14).

3. Results

3.1. Current Status of Population Distribution and Spatial Distribution of Public Service Facilities in Chengdu

According to the Seventh Census in 2020, the population of Chengdu's 12 municipal districts is nearly 15.4 million, and Figure 3 shows the distribution of population density in Chengdu as of 2020. As shown in Figure 3, the population density of Chengdu City decreases from the city center to the outskirts of the city, and most of the densely populated neighborhoods are located within the elevated second ring road. These densely populated areas overlap with the traditional urban center of Chengdu.

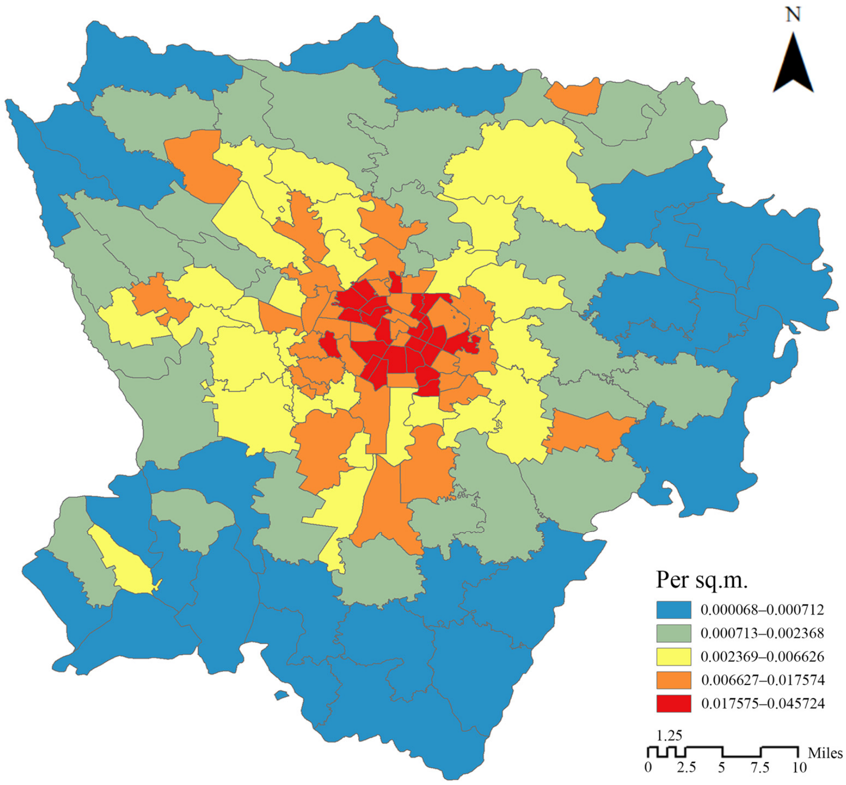

Figure 3. Spatial distribution of population density in Chengdu in 2020.

Overall, the spatial distribution of most public service facilities is relatively uneven (Figure 4), with high density areas concentrated in the city center, and the density gradually decreasing in all directions (Figure 5). This is similar to the distribution of population density in Chengdu (Figure 3). Among the five types of public service facilities, the spatial distribution of education and transportation public service facilities is the most balanced, while the distribution of medical facilities is the most inequitable. The density of facilities within different community living circles is distributed in a circular pattern, decreasing significantly from the center to the periphery.

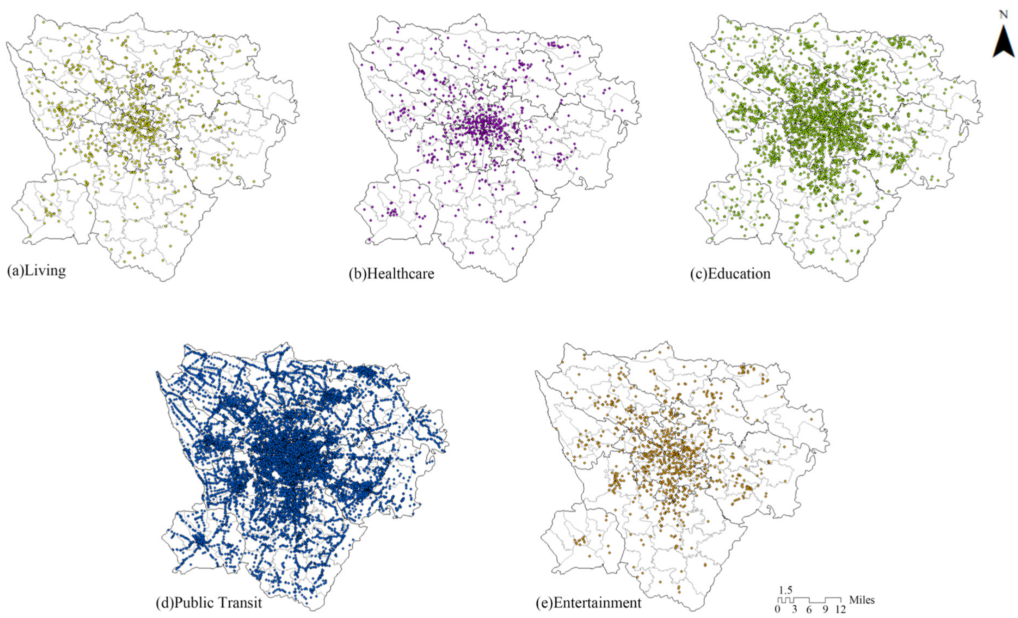

Figure 4. The spatial distribution of various PSF.

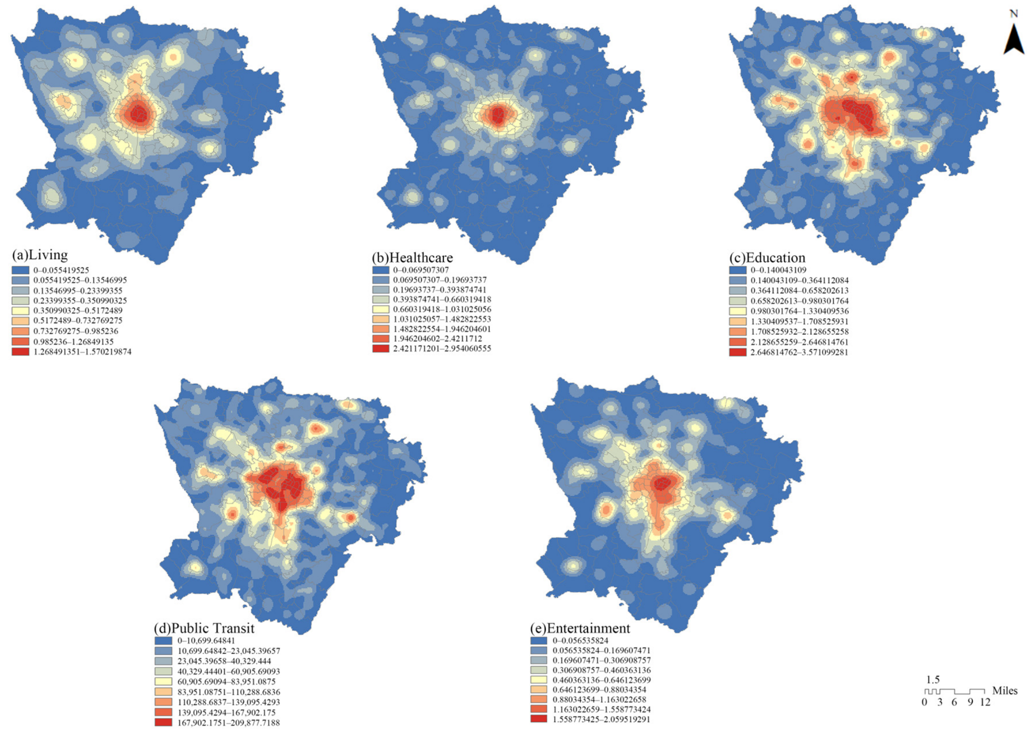

Figure 5. Kernel density analysis for 5 types of public service facilities.

3.2. Spatial Distribution of Accessibility

Based on the accessibility evaluation results obtained from Ga2SFCA, the accessibility of all facilities is categorized into five levels, i.e., low, relatively low, medium, relatively high and high, using geometric intervals in ArcGIS. Figure 6 shows the distribution of 15-minute accessibility for locations related to living, education, healthcare, transportation and entertainment in Chengdu, with redder colors indicating higher 15-minute accessibility.

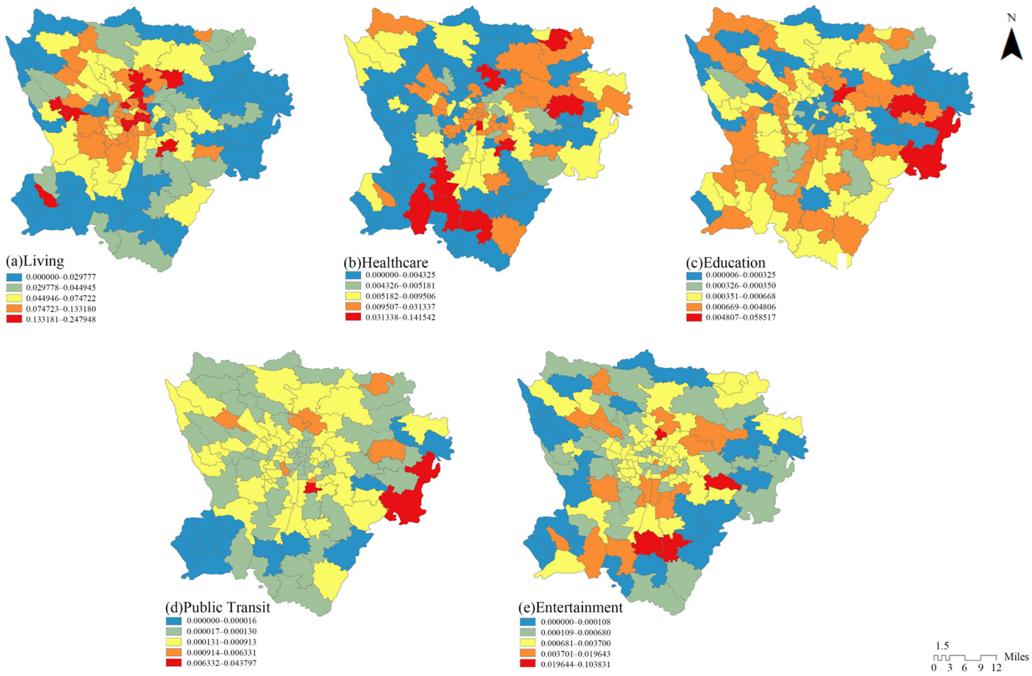

Figure 6. Distribution of 15-minute accessibility related to (**a**) living; (**b**) healthcare; (**c**) education; (**d**) public transit; and (**e**) entertainment.

As can be seen from Figure 6, the spatial heterogeneity of 15-minute accessibility of various public service facilities in Chengdu is large. The 15-minute accessibility of education and public transportation facilities is more evenly distributed, with 30.1% of streets having high transportation and high education accessibility, and 84.5% of streets having public transportation accessibility located in the low and medium bands. Healthcare facilities have the greatest spatial variation in accessibility.

As shown in Figure 6a, the streets with higher life accessibility are concentrated in the Shuangliu District, Pidu District and Qingyang District. As shown in Figure 6b, the distribution of educational resources in each district of Chengdu City is more balanced, and most streets enjoy better accessibility to educational resources. This reflects that Chengdu city is better developed in the construction of kindergartens, primary and secondary schools. The weaker accessibility of education resources within the elevated second ring road area may be due to having higher population density, but the site functions are dominated by government land and commercial land, with less land for education. As shown in Figure 6c, streets with high medical accessibility are almost exclusively located within the third ring road of Chengdu. This suggests that medical resources in Chengdu are still overwhelmingly concentrated in traditional city centers such as Xiyuhe Street and Yulin Street (southern part of the elevated second ring road). In addition to this, there are also some streets in the outskirts of the city that have high healthcare accessibility. This may be due to the fact that they have a smaller population than traditional city centers and are close to the people's hospitals in the districts. Figure 6d shows that most streets in Chengdu enjoy good accessibility to public transportation, except for most streets in the Xinjin District. This is due to the construction of an efficient public transportation system in Chengdu City. A total of 12 metro lines, 281 metro stations and 979 bus lines can provide convenient public transportation travel services to most streets in Chengdu City [46]. Finally, Figure 6e shows that even in the outskirts of Chengdu City, there is a high level of recreational accessibility. This is due to the fact that in addition to Chengdu citizens' habits of drinking tea and playing mahjong, the city has built many ecological parks and sports parks that can provide residents with places to relax.

In order to have a comprehensive understanding of the comprehensive accessibility of public service facilities within the 15-minute living circle, this study weighted the accessibility of each type of facility using the expert scoring results obtained from the hierarchical analysis method and obtained the 15-minute comprehensive accessibility of public service facilities (Figure 7).

Comprehensive accessibility roughly shows a spatial pattern of high in the central city and low in the periphery of the city. Places with high comprehensive accessibility are mainly concentrated in the intersection of the four districts of Jinjiang, Jinniu, Wuhou and Qingyang, such as Chunxi Road Street, Shaocheng Street and Hongpailou Street (area A in Figure 7). They are located in the historical population center and experienced the earliest urban development in Chengdu, which laid a better historical foundation for building basic urban functions such as living, medical care and entertainment. In addition to this, famous historical and cultural attractions and entertainment venues such as the Wuhou Temple, Kuan-Narrow Alley, and Taikouli, are located here. Chengdu's efforts to develop the city as a tourist destination have also strengthened the construction of supporting facilities in the area, leading to a high level of comprehensive 15-minute accessibility.

Combined with the population distribution in Figure 3, we find different reasons for the low comprehensive accessibility. For example, in the northwestern part of the Pidu District, the southeastern part of the Qingbaijiang District, and most of the streets in the Xinjin District belong to the suburbs of the city, with relatively small residential populations and low demand for public service facilities. At the same time, due to the distance from the city center, the infrastructure support is not good enough, resulting in a lower 15-minute comprehensive accessibility. In contrast, the Jumping Stirrup River, Fuqing Road and Wannianchang neighborhoods in the southwestern part of the Chenghua District (the area B in Figure 7) have some degree of public service facility provision. However, these areas are densely populated and place higher demands on infrastructure development, resulting in lower accessibility.

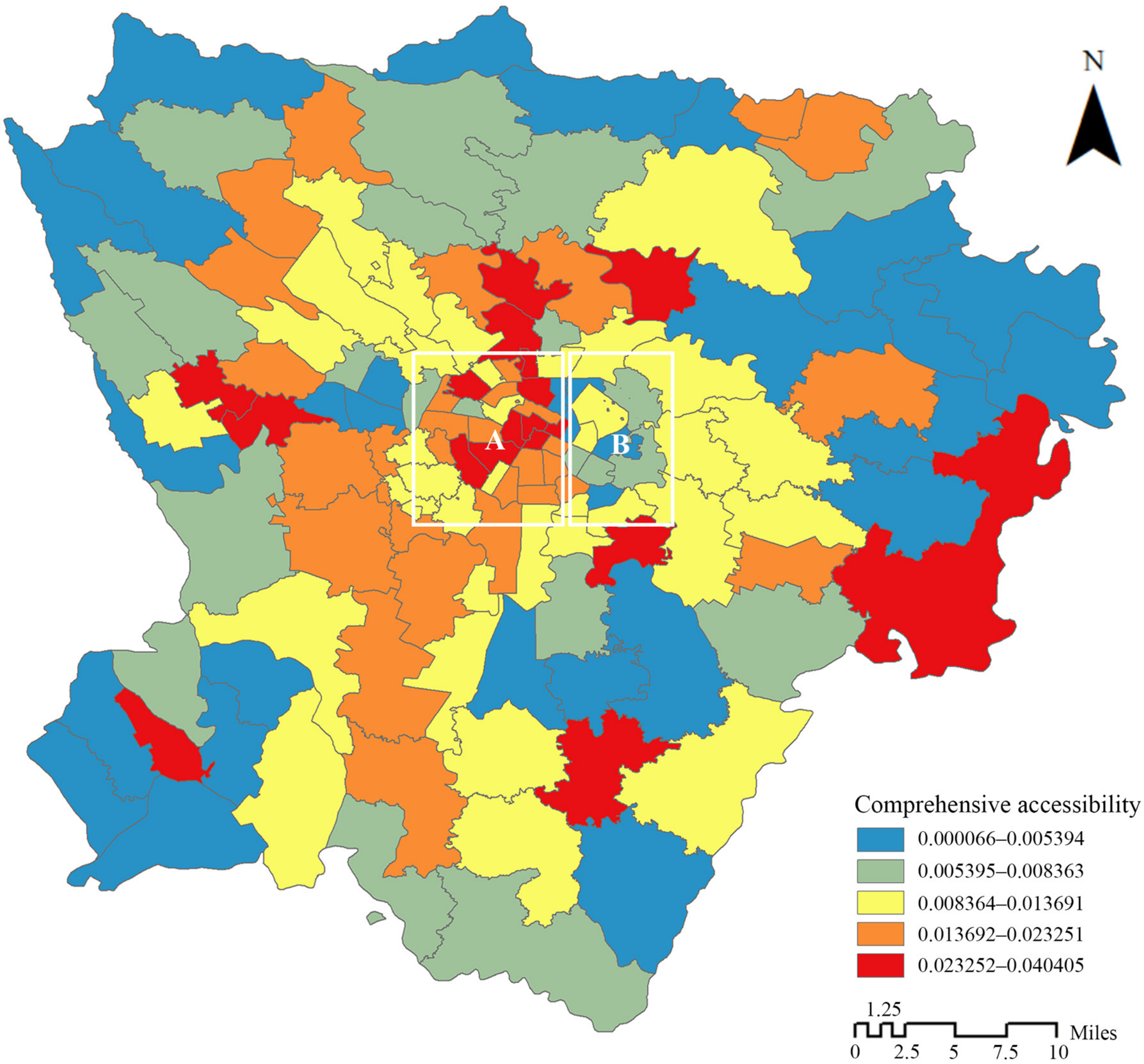

Figure 7. Comprehensive 15-minute accessibility to public services facilities.

3.3. Spatial Matching of Population Density and Accessibility

In the actual utilization of public service facilities, apart from the degree of provision of public service facilities as measured by accessibility, the degree of demand of the population is also taken into account. This study utilized bivariate spatial autocorrelation by measuring the spatial correlation between 15-minute composite accessibility and population density and categorized the spatial associations between the two variables into five categories: high density—high accessibility, low density—low accessibility, low density—high accessibility, high density—low accessibility, and non-significant. Among them, both high density–high accessibility and low density–low accessibility indicate spatial matches, and both low density–high accessibility and high density–low accessibility show spatial mismatches. In this case, low density–high accessibility shows a spatial mismatch of oversupply and high density–low accessibility shows a spatial mismatch of undersupply. Non-significance indicates that the relationship between facilities and population density is random.

As shown in Figure 8a, the global Moran index is 0.2687 (z = 6.7899, $p < 0.001$), indicating that there is a spatial positive match between population density and 15-minute integrated accessibility in Chengdu.

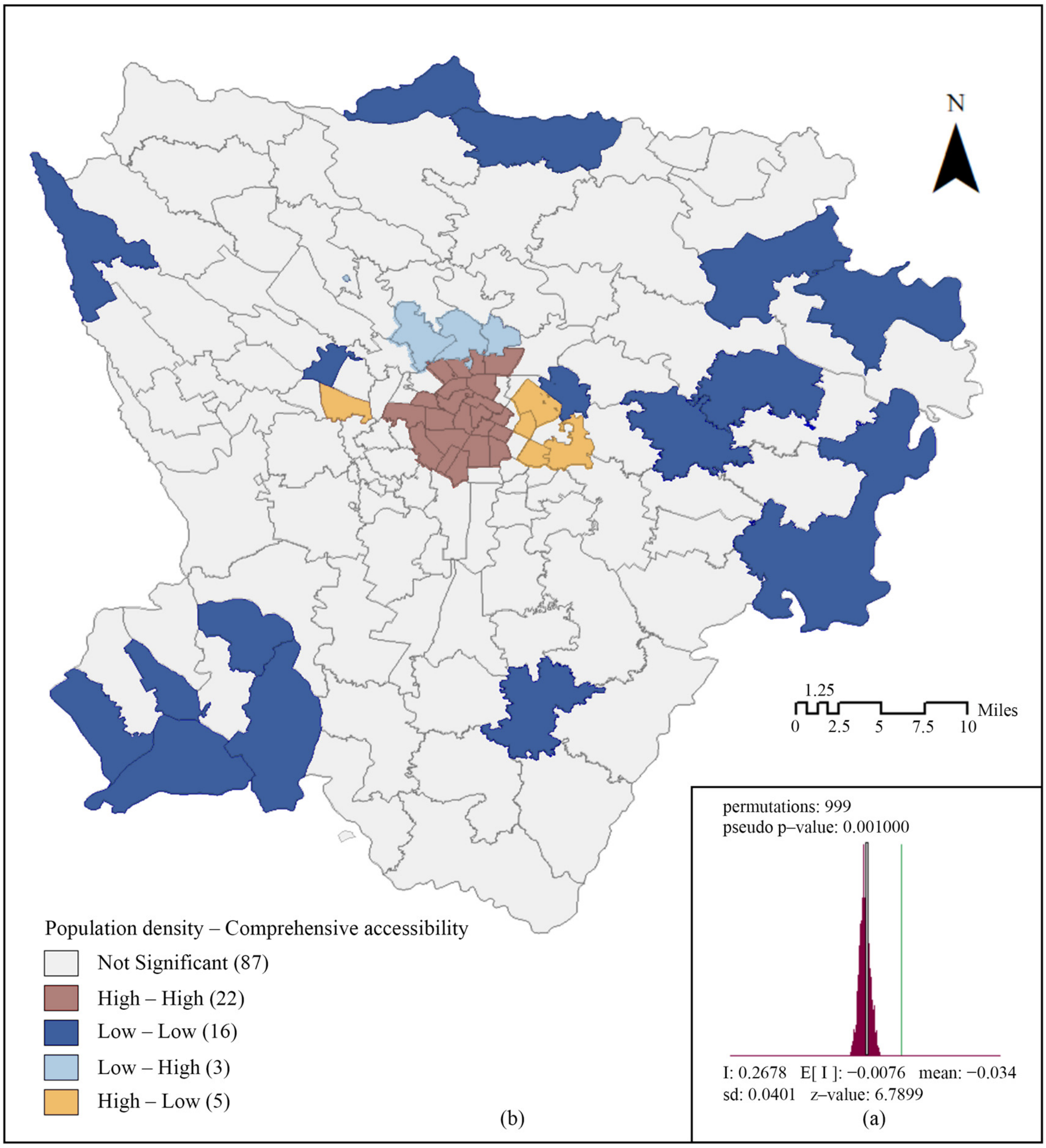

Figure 8. Results for bivariate spatial autocorrelation. (**a**) Moran index; (**b**) results of spatial matching of population density and integrated accessibility.

As shown in Figure 8b, only 16.5% of the streets in Chengdu city are spatially positively matched, 2.3% are spatially positively matched with oversupply, 3.8% are spatially negatively matched with undersupply, and 12% are spatially negatively matched. Taken together, the population density and comprehensive accessibility of streets in Chengdu city show a significant spatial mismatch. The undersupply zone (high density–low accessibility is concentrated in the area of Jumping Stirrup River Street, Shahe Street and Baohe Street at the edge of the third ring road, and the spatial negative correlation matching zone is mainly concentrated in the suburban areas at the periphery of the city. The spatial positive correlation matching area is concentrated in the central and western part of the third ring road.

4. Discussion

4.1. Factors Affecting the Spatial Distribution of Facilities

In general, the spatial distribution of public service facilities is influenced by urban planning policies and the nature of land use. Since people have different needs for different kinds of public service facilities, the intensity and number of different kinds of facilities are not the same. It can be seen through Figures 4 and 5 that the central area of the city is the center of urban politics, commerce, culture, etc., with dense population, high development intensity, and intensive public service facilities. In detail, the eastern part of the study area is adjacent to the Longquanshan Natural Scenic Area; the western part of the area focuses on the protection of ecological resources and is in the restricted development zone in the urban planning, so the development intensity is low, the population is small, and accordingly the distribution of public service facilities is also sparse. The southern part of the study area, such as the Shuangliu and Xinjin districts, is part of Chengdu's "Southern Expansion" area, which focuses on the development of high-tech industries and the new economy. However, parts of Shuangliu and Xinjin were first proposed as Tianfu New Zones in Sichuan Province in 2010, and following this planning and construction began, so public service facilities in these areas need to continue to be improved.

The results of the bivariate spatial autocorrelation indicate that there is a spatial positive correlation between population density and 15-minute composite accessibility in Chengdu, but the spatial positive correlation is weak, which suggested that more populated neighborhoods do not necessarily imply higher spatial accessibility. In general, the government tends to set up more public service facilities in densely populated areas to protect the daily needs of residents. Therefore, the weak positive spatial correlation between the two indicates to a certain extent that there is a mismatch between the facilities and the spatial distribution of the population, and that the public service facilities of 15-minute communities in Chengdu are still not well constructed outside of the center of the city.

The current findings show that the area within the elevated second ring road (the central city) in Chengdu has a high 15-minute composite accessibility and is the only area in the study area where population density and 15-minute composite accessibility are spatially positively matched. Compared with other areas in Chengdu, the central city has a deeper construction base as it is a historical center of population and development dating back to the Qin and Han Dynasties. As a result, the density and sophistication of public services such as healthcare, transportation, and recreation are much higher. It is worth noting that the outer fringes of the elevated second ring road (e.g., Jumping Stirrup River Street, Shahe Street, and Baohe Street) have relatively low comprehensive 15-minute accessibility and an undersupply of amenity resources in terms of spatial distribution. This suggests that the development in this historical urban area still has a positive influence on the current central city 15-minute living area construction.

In addition to the central city, there are also high 15-minute comprehensive accessibility in areas such as Huangjia Street and Dongsheng Street in the Shuangliu District, Liucheng Street and Yongquan Street in the Wenjiang District, and Pidu Street in the Pidu District. The distribution of these high accessibility areas matches the spatial distribution of the 110 neighborhood community complexes already in operation in 2023 [47]. The construction of neighborhood community complexes, which began in 2010, advocates for the concentration of scattered and distributed community services in a cluster of buildings or on a single piece of land in each community, thereby addressing the shortage of public services and inadequate provision of public transportation. The high 15-minute comprehensive accessibility of these areas in this study suggests that neighborhood community complexes can, to a certain extent, help residents living in the neighborhood to access basic living services within a short walking distance.

It is also worth noting that in comparison with other city cases, we found that although the high 15-minute comprehensive accessibility areas in different cities are located in different parts, the factors affecting the spatial distribution are similar. For instance, Fuzhou and Chengdu have a similar spatial distribution trend of infrastructure point distribution, i.e., the density of facilities is highest in the city center and decreases from the city center to the periphery [48]. Yet, Hong Kong has high comprehensive 15-minute accessibility to historical population centers (e.g., Yau Tsim Mong in the Kowloon region, and the northern Central and Western and Wan Chai areas on Hong Kong Island) [49]. Additionally, compared with non-coastal areas, Hong Kong has a better allocation of educational, recreational and public transportation facilities in the more economically developed coastal areas and at famous scenic spots. This suggests that the distribution of 15-minute comprehensive accessibility may be related to the city's historical development, economic level, cultural and tourism development, as well as other factors.

4.2. Suggestions for Improving the Current 15-Minute Living Circle in Chengdu

Based on the current study, this paper proposes feasible suggestions for optimizing the 15-minute living circle in Chengdu. First, it should focus on areas where demand exceeds supply. In areas with a huge population, even relatively higher facility densities and numbers of facilities do not mean that more adequate services can be provided, and the bivariate local spatial autocorrelation directly reflects this undersupply relationship. City planners and managers who make decisions based solely on the number or density of facilities may be underserved by the community's infrastructure. Therefore, more public service facilities should be considered and provided according to the actual demand in the region.

The second is to strengthen the construction of neighborhood center complexes. The planning of community living areas encourages the mixed use of land to improve the functional utilization of land and to enhance the linkage of various urban functions. At the same time, it may be difficult to directly add new public service facilities in built-up urban areas due to limited undeveloped land. Therefore, mixed land use and enhanced construction of neighborhood center complexes to integrate the basic functions of each city may be one of the important ways to solve this problem. For example, the vacant land around bus stops and subway stations can be used to build corner plazas and pocket parks, which can enhance the greenery within the living circle to a certain extent, and also increase the number of social places. In addition, Chengdu's elderly population accounts for 20.61% of the household population in 2021, and has entered a deeply aging society [50]. In the future, senior living facilities can be combined with medical facilities to promote the construction of high-quality senior living and medical integrated service facilities.

Thirdly, in optimizing the spatial layout of public service facilities, more in-depth research should be conducted on local residents, so that the construction of public service facilities can be strengthened in a targeted manner. Currently, Chengdu is making up for the shortcomings in the construction of public service facilities and is also carrying out pilot construction in 12 communities, including the Jincheng community and the Luhu Park community. Therefore, public participation in planning is necessary. The government can collect more detailed data on travel and facility utilization from local residents through questionnaire surveys and interviews, so as to provide basic information for a more accurate assessment of accessibility and facility location. In addition, attention should be paid to the needs of vulnerable and marginalized groups such as children, the elderly and the disabled, which is one of the requirements of social justice.

4.3. Main Contributions to Existing Research

This study built a framework for assessing the current status of spatial distribution of public service facilities, which measures the 15-minute accessibility of basic public service facilities in a more comprehensive way and bridges the gap of previous single-type studies that are difficult to make comprehensive optimization recommendations directly. Meanwhile, the bivariate spatial autocorrelation reveals the areas of mismatch between supply and demand more accurately, and more clearly shows the areas that need to be focused on for optimization by policy makers.

Different public service facilities have different spatial distribution patterns in the city, so it is inaccurate to measure the configuration of public service facilities in the 15-minute living area through a single facility. For example, streets within the elevated second ring road area of Chengdu have good 15-minute accessibility to living, healthcare, public transportation and recreational facilities, but are slightly lacking in accessibility to educational resources. Most of the streets in the Xinjin District are better equipped with educational resources, reaching a medium-high level within the study area, but the accessibility of the other four categories of urban functions lags behind other neighborhoods, thus presenting a low comprehensive 15-minute accessibility. The above findings yielded similar results in other studies. For example, 15-minute accessibility in Hong Kong has different distributions in five categories of POIs [49]. In Fuzhou, the 14 subcategories of basic service facilities show similar spatial distribution characteristics, but there are still differences in the spatial layout with the three major categories of service facilities, such as cultural and educational integrated services [48]. This study not only calculates the 15-minute accessibility of each category of public service facilities, but also calculates the 15-minute comprehensive accessibility. These indicators can complement each other and together reveal the current situation of public service construction in the 15-minute living area of Chengdu.

While 15-minute accessibility can show where single or multiple types of public services are less accessible, the policy implications of this result should be interpreted and applied with caution. For example, there are streets with fewer residents and lower demand that result in lower spatial accessibility, so it is not useful to increase the number of public services in such areas. Such areas can be identified using bivariate spatial autocorrelation, which highlights areas where additional public services are truly necessary (i.e., high density–low accessibility areas), allowing the government to target additional public services to avoid unnecessary waste.

Moreover, the AOI and road network data come from the Baidu Open Platform and OSM, respectively. The geographic data on these two platforms have a wide range of coverage and comprehensive data types, which are openly accessible and dynamically updated. Thus, the methodology and framework of this study could be easily used to inform similar surveys conducted in other cities in China.

4.4. Limitations

There are also some limitations in this study. First, in the accessibility calculations, the supply capacity of the facilities is described only in terms of area, and the functional breakdown of each facility is not taken into account; e.g., the supply capacity of general hospitals and specialty hospitals is considered to be the same in the accessibility calculations of this study. However, in some cases, specialty hospitals may not be able to provide the full range of medical care, and nearby residents must choose other hospitals, which sometimes have lower accessibility. It is also difficult for us to calculate in more detail the size of various public service facilities through such indicators as the number of students enrolled in schools, the number of beds in hospitals, and the patronage of public transport. Second, this study only considered physical accessibility; i.e., accessibility was measured based on distance from the road network alone and did not take into account potential psychological factors for residents, such as the fact that some populations may have a place attachment to parks that are further away from their homes, or that these further parks have a better quality of environment and more recreational/sports facilities. Third, this study ignores differences in demand across age groups (e.g., it is unreasonable to consider infants and toddlers to use senior living facilities) and differences in travel ability (e.g., biking, walking, driving). Future research could consider calculating the weights of accessibility and demand based on different age groups, and thus refine the framework for measuring comprehensive accessibility. In addition, residents' behavioral data such as cell phone signaling data or tracking surveys can be used in future studies to measure the actual use of public service facilities.

5. Conclusions

In this study, the 15-minute accessibility of 5 types of public service facilities was measured by Gaussian two-step moving search method using the major 12 municipal districts in Chengdu as an example, and the weights obtained from the hierarchical analysis method were weighted to further obtain the 15-minute composite accessibility. Finally, the degree of matching between facility resources and population is discussed in conjunction with bivariate spatial autocorrelation. Finally, an optimization strategy for 15-minute living area planning is proposed. The main results and findings are summarized below.

(1) The spatial heterogeneity of facility distribution in the study area is large. The overall distribution of facilities shows a spatial distribution pattern of high in the center and low in the surrounding areas, and the 15-minute comprehensive accessibility shows a spatial distribution pattern of high in the city center, southwest, and northwest, and low in the suburbs of the city.
(2) There is a mismatch between the supply and demand of basic service facilities and the population in Chengdu, and the areas with sufficient supply are only concentrated within the elevated second ring road of the city.
(3) By comparing with other previous city study cases (Fuzhou, Hong Kong), we found that the spatial distribution of public service facilities and 15-minute accessibility in different cities are affected by similar factors, all of which are related to the location of the central city, the level of economic development, and the historical and cultural heritage.
(4) In order to further improve the construction of the 15-minute living area, firstly, attention should be paid to areas where demand exceeds supply, and public service facilities should be appropriately increased. Secondly, the construction of neighborhood center complexes should be strengthened to increase the rate of land function mixing. In addition, public participants should be used to assist planning.
(5) We built a framework for assessing the current status of spatial distribution of public service facilities, which measures the 15-minute accessibility of basic public service facilities in a more comprehensive way and bridges the gap of previous single-type studies, which make it difficult to make comprehensive optimization recommendations directly.
(6) The research framework of the current study can identify more precisely the vulnerability areas that need to be focused on. In addition, the methodology of this study is highly replicable in other cities in China, providing practical ideas for similar studies.

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

Funding: The authors declare that financial support was received for the research, authorship, and/or publication of this article. This work was supported by Sichuan Philosophy and Social Science Foundation Project (Grant No. SCJJ23ND494), and Central Universities Basic Research Operating Expenses–Science and Technology Innovation Project (Grant No. XJ2023009801).

Data Availability Statement: The raw data supporting the conclusions of this article will be made available by the authors on request.

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

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