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Spatial-Performance Evaluation of Primary Health Care Facilities: Evidence from Xi'an, China

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Abstract: Primary health care (PHC) facilities play a significant role in constructing a "people-oriented city" to promote sustainable urban development. However, existing studies exhibit gaps in the spatial-performance evaluation of PHC facilities at the block scale and in identifying spatial association types between facilities and the population. Therefore, we examined the elderly population, who rely heavily on PHC facilities, and developed a spatial-performance evaluation model for PHC facilities at the block scale using the Ga2SFCA method and the bivariate spatial autocorrelation method. The results revealed an evident concentric pattern and spatial mismatch between the accessibility of facilities and the elderly population. Facilities in the central area were inadequate due to the excessive density of the elderly population, whereas medical services in suburban areas were unsustainable due to poor accessibility. From a spatial-justice perspective, the spatial-performance evaluation at the block scale can identify spatial correlation types and distribution characteristics between PHC facilities and the elderly population.

Keywords: PHC facilities; spatial-performance evaluation; elderly population density; Xi'an

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1. Introduction

As a crucial element of public services, PHC reflects the sustainable development of cities [1,2]. The elderly population, being a significant group heavily reliant on PHC facilities, must be thoroughly considered in terms of the spatial layout and refined management of these facilities [3]. China is experiencing rapid growth in its aging population. In 2020, individuals aged 60 and above comprised 18.7% of the total population on the Chinese mainland. In encountering the challenge of population aging [4], it is necessary to examine and optimize the spatial layout of PHC facilities [5,6]. The effective configuration of PHC facilities has become the core issue of current research. The spatial matching of facilities with the population is conducive to improving resource-use efficiency and avoiding spatial mismatches of an excess or undersupply of facilities [7–9].

The spatial distribution of the population directly affects the spatial performance of facilities [7,10,11]. The spatial performance of PHC facilities has been evaluated in terms of resource quantity [12], spatial distribution [13], and supply–demand balance [14]. As a social resource with significant spatial attributes, PHC facilities must not only focus on place-based and people-oriented equality but also on people's usage needs and spatiotemporal differences to achieve spatial justice [15]. Spatial justice refers to ensuring fairness and equality in citizens' spatial rights and interests within the domains of spatial production and spatial resource allocation. It encompasses justice in all aspects of spatial resources and spatial products, including their production, possession, utilization, exchange, and consumption, aiming to foster balanced social spatial development and equitable resource distribution. Since older individuals have a greater demand for PHC services around their living spaces in their daily lives than younger people [16–18], it is necessary, within the framework of spatial justice, to ensure the full entitlement of a spatial supply of PHC facilities to effectively address the issue of population aging. However, little is known about the types of spatial correlation and distribution characteristics between PHC facilities and the elderly population distribution [5]. Further, "people's city" is a concept that emphasizes the people-centeredness in urban planning and development. It aims to create cities that meet the needs and aspirations of the residents, ensuring their well-being and happiness. This concept emphasizes the importance of building inclusive, accessible, and sustainable cities, providing equal opportunities and high-quality public services for all [4,5,19]. In the context of constructing a "people's city", we have to ask how their spatial performance is and whether the spatial distribution of PHC facilities is equitable [20].

Spatial-performance evaluation is an assessment of how well facilities or services align with the population in spatial allocation (i.e., effectiveness). Existing research has mainly been based on methods such as buffer analysis [10,21,22], gravity models [23–25], potential models [26], and 2SFCA models [1,5,27–33], attempting to explain the spatial accessibility of facilities. In general, 2SFCA models are more practical, understandable, and implementable than other models and are frequently used in accessibility evaluation. These models consider competition among multiple demand points, establish a search threshold [8,9,13,34,35], and provide methodological support for this study.

The scale affects the accuracy of spatial-performance evaluation results. However, public service spatial-performance evaluation is rarely analyzed at microscales, such as blocks or buildings [3,26,36,37]. Spatial-performance evaluation based on a larger city scale tends to be biased (over- or under-estimated) when reflecting specific geographic differences [36,38]. The 15 min pedestrian-scale neighborhood, as the main place for daily activities, is the spatial distance threshold for daily medical-treatment behavior [39]. Therefore, spatial-performance evaluations based on the block scale can more accurately reveal spatial inequalities at microscopic geospatial levels [40,41].

Providing the elderly population with convenient and equal access to public services is an important goal in the construction of a "people's city" in China. The equalization of PHC facilities has become a crucial aspect in addressing the health care needs of the elderly [42,43]. The spatial-performance evaluation of PHC facilities at the block scale can help optimize their spatial layout, achieve spatial equality and justice, and promote sustainable urban development [2]. Therefore, using Xi'an as an example, the spatial performance of PHC facilities was evaluated with the aim of establishing a spatial-performance evaluation framework at the block scale, reflecting spatial justice in the distribution of PHC facilities, and enhancing the level of urban-refinement management.

2. Methods and Materials

2.1. Study Area

Xi'an is the 9th largest central city in China. Over the past few decades, Xi'an has undergone significant changes in the age composition and quantity of the population, as well as the layout of PHC facilities. The urban area in Xi'an was approximately 641 km^2 with a population of about 6.7 million in 2022. As the proportion of people aged 60 and over in Xi'an reached 16.02% according to the 7th National Population Census (the standard time point of the census is 0:00 on 1 November 2020), Xi'an has become an aging city. Due to the spatial disparity in the distribution of medical facilities, coupled with the unequal distribution of the population accessing these facilities, there is a pronounced inequality in the allocation of medical resources in Xi'an.

Approximately 81.64% of the population can only access 54.88% of the medical resources [44], thereby exerting a negative influence on the sustainable development of the city. Therefore, it is representative and typical to use Xi'an as an example for research on the spatial performance of PHC facilities.

Blocks, formed by the division of road networks, serve as the basic units of residents' cognition and socioeconomic functions, while also acting as the spatial carrier of urban texture and urban management [36,45]. Compared with grids [35], blocks have stronger interconnectivity and are more conducive to refined urban management. Therefore, this study employs blocks as the basic spatial-analysis unit. The central urban area of Xi'an was divided into 1251 blocks using road network data. Meanwhile, it was divided into four geographical zones: Zone I, Zone II, Zone III, and Zone IV, based on the urban ring road network (Figure 1).

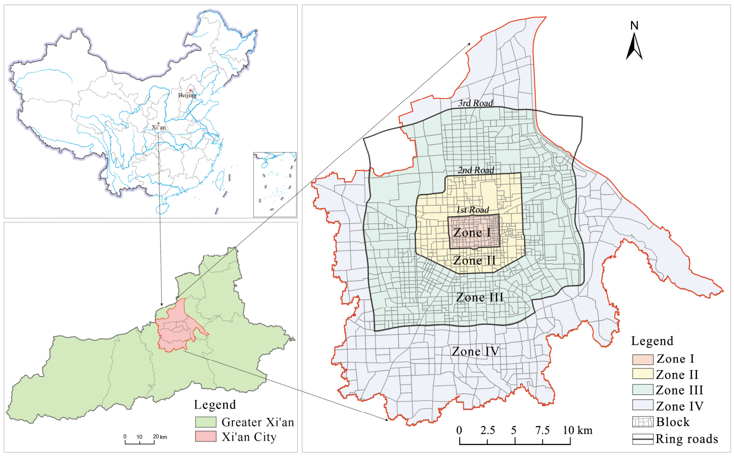

Figure 1. The study area.

2.2. Data Sources

The PHC facilities data were sourced from the POI data of Xi'an in June 2023 (Table 1). First, the POI data underwent initial coordinate correction, cleaning, and filtering, resulting in the acquisition of 2963 PHC facilities' POI data (Table 2). Second, a basic database of PHC facilities was constructed by integrating urban-planning data from Xi'an using ArcGIS 10.5 (Figure 2).

Table 1. Datasets and sources used in the study.

Category	Datasets	Format	Sources
PHC facilities data	POI	Vector (Point)	Baidu Map Services, China
	Urban-planning data	Raster	Urban Master Plan of Xi'an (2008–2020)
Urban roads data	Urban road network	Vector (Polygon)	Open-source map
The elderly population data	Baidu heat map	Raster	Baidu Map Services, China
	Population Census data	Table	7th National Population Census

Table 2. Number of PHC facilities in Xi'an.

Zone	Area (km^2)	Number of Block Units	PHC Facilities	
			Number	Density (per km^2)
I	13.24	143	197	14.88
II	62.73	250	681	10.86
III	246.56	632	1441	5.84
IV	318.42	226	644	2.02
Total	640.95	1251	2963	

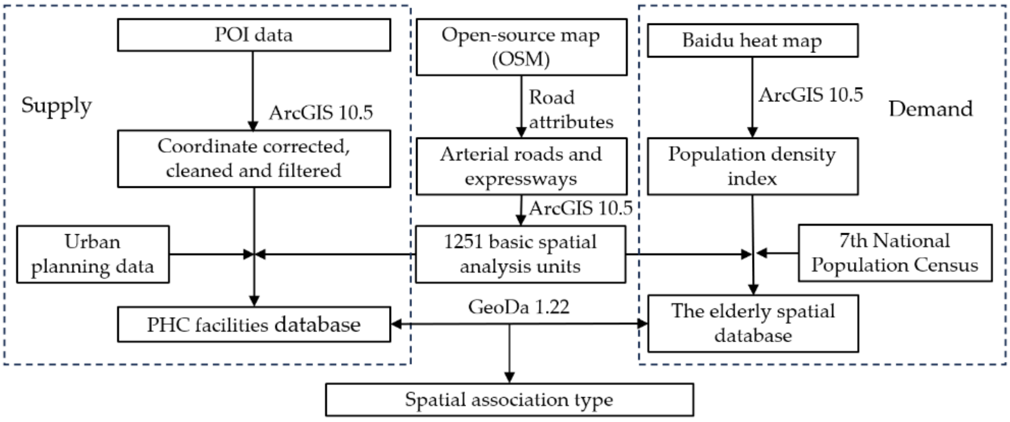

Figure 2. Data-processing flowchart.

The urban road data were obtained as vector data from the open-source map (OSM) in 2023 (https://www.openstreetmap.org, accessed on 6 June 2023) (Table 1). First, urban arterial roads and expressways were re-identified based on road attributes. Secondly, 1251 basic spatial-analysis units were created by dividing urban blocks along roads with distinct spatial boundaries, leading to the establishment of the basic spatial-analysis-unit database (Figure 2).

The elderly population data were obtained from the Baidu heat map and the 7th National Population Census. Different colors on the Baidu heat map represent different values of population density (The population density represented by different colors is based on Baidu's official legends. Among them, the red indicates a population density of 60/hm^2, the orange of 40–60/hm^2, the yellow of 20–40/hm^2, the pale green of 10–20/hm^2, and the deep green of <10/hm^2). Previous research has shown that urban-population activities exhibit cyclical changes on a daily (morning, afternoon, evening, and night) or weekly (weekends and weekdays) basis [19,46]. Therefore, the specific steps for measuring a dynamic elderly population were as follows. First, 18 Baidu heat maps were obtained by intercepting data from the Baidu heat map from 7:00 to 23:00 every two hours on 6 June (Tuesday) and 10 June (Saturday) 2023. Second, the population spatial-distribution database was constructed by identifying the color and pixel size of the spatial-analysis unit. Third, using the proportion of the elderly population in each district of Xi'an from the 7th National Population Census data, the population spatial-distribution data in the Baidu Heat Map were revised to construct a spatial database of the population aged 60 and above (Figure 2). It should be noted that the population density index is a relative value, not an absolute value, representing the relative relationship of population size among different spatial units. Moreover, as a correction coefficient for population size, the proportion of the elderly population reflects the aging situation of spatial units as much as possible, but it is not an absolute size of the elderly population.

The formula for the population density index of the elderly is as follows:

$$Q = \frac{\sum_{i=1}^{m} a_i \times b_i \times c}{S} \tag{1}$$

$$N = \frac{Q_{tk}}{\sum k \times Q_{tk}} \times \alpha \tag{2}$$

where Q is the population density at a certain time, a is the population-density value represented by the i-th color, b is the number of pixels associated with the color, c is the area of a single pixel, S is the block area, m is the type of color, N is the population heat index, Q_{tk} is the population density of block k at time t, and α is the aging proportion of the block k.

2.3. Methods

2.3.1. Ga2SFCA

Spatial accessibility is a prerequisite for residents to access health care facilities. It not only reflects spatial distribution but also affects facility utilization [15,46]. Increasing accessibility reduces the distance patients need to travel to seek health care, whether it be diagnosis or treatment services. The service capacity of the facility was measured by using the Gaussian 2-step floating catchment area method (Ga2SFCA) to evaluate spatial accessibility in two steps [47]. Step 1 involves taking the location of the PHC facility as the center point and calculating the supply and demand ratio of the facility within a given spatial function threshold. Step 2 measures the accessibility of PHC facilities in blocks within the spatial domain measured from the center of the urban block in which the population needs PHC services (Figure 3). In this research, a Gaussian function is used to continuously account for the distance decay of accessibility within a catchment. The formula is the following:

$$R_i = \frac{S_h}{\sum_{k\in\{d_{kh}\le d_0\}} G(d_{kh}, d_0)PI_k} \quad (3)$$

$$G\left(d_{ij}, d_0\right) = \begin{cases} \frac{e^{-\left(\frac{1}{2}\right)\times\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\left(\frac{1}{2}\right)}}{1-e^{-\left(\frac{1}{2}\right)}}, if\ d_{kj} \le d_0 \\ 0\ , if\ d_{kj} > d_0 \end{cases} \quad (4)$$

$$A_k = \sum_{l\in\{d_{kl}\le d_0\}} G(d_{kl}, d_0)R_l \quad (5)$$

where S_h is the service capacity index, expressed as the number of PHC facilities; R_i is the supply–demand ratio of PHC facilities; d_{kh} is the spatial distance from the center of block k to the center of PHC facility h; PI_k is the population index of block k within the spatial domain of PHC facility h ($d_{kh} \le d_0$); $G(d_{kh}, d_0)$ is the Gaussian equation with spatial friction properties; d_0 is the spatial distance threshold, according to the "Standard for Urban Residential Area Planning and Design" (GB50180-2018) [48], combined with the concept of Xi'an's "15-min Convenient Medical Circle"; the value of d_0 is 1 km in the study; A_k is the accessibility of PHC facilities in block k; l is a PHC facility in the set of PHC facilities within the spatial domain of block k ($d_{kl} \le d_0$); d_{kl} is the distance from block k to PHC facility l; $G(d_{kl}, d_0)$ is the coefficient of spatial friction between PHC facility l and block k; and R_l is the supply ratio of PHC facility l (Figure 3).

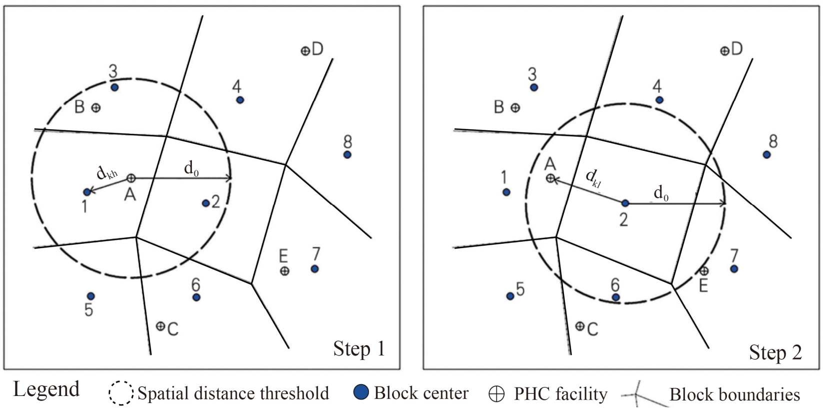

Figure 3. Schematic of Ga2SFCA.

2.3.2. Spatial Autocorrelation

Global spatial autocorrelation describes the spatial features of geographic feature attribute values across the entire region. The global Moran index formula is the following:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}(x_i - \overline{x})(x_j - \overline{x})}{\left(\sum_{i=1}^{n}\sum_{j=1}^{n}W_{ij}\right)\sum_{i=1}^{n}(x_i - \overline{x})^2}, (i \neq j) \tag{6}$$

where $Moran's\ I$ is the global Moran index; W_{ij} is the spatial weight matrix using Euclidean distance; x_i is the value of variable at location i; $\overline{x}$ is the average value of a variable; and n is the number of evaluation units.

Bivariate local spatial autocorrelation is commonly used to analyze the spatial correlation between two variables, typically characterized by binary local Moran's I [49]. In this study, it was utilized to assess the spatial correlation between facility accessibility and the population density index and its degree of correlation, as well as to identify the spatial-correlation pattern. The formula is the following:

$$I_{xy}^{i} = z_x^i \sum_j w_{ij} z_y^j,\ \sum_j w_{ij} = 1 \tag{7}$$

where I_{xy}^{i} = the local spatial autocorrelation coefficient of spatial analysis unit i; z_x^i = the standard value of variable x (elderly population density index) of spatial analysis unit i; w_{ij} = the spatial weight matrix using Euclidean distance; and z_y^j = variable y (accessibility y of PHC facilities) of area j.

3. Results

3.1. Spatial Characteristics of the Elderly Population

The distribution of the elderly population exhibits characteristics of higher density in the central area compared to the suburbs, demonstrating a significant monocentric structure (Figure 4). From the city center outward, the elderly population density index gradually decreases in Zone I (average value 0.0062), II (0.0045), III (0.0018), and IV (0.0006). Spatial-analysis units with higher elderly population density are mainly concentrated in the southeast of the city center (Zones I and II), while those with lower elderly population densities are mainly concentrated in the suburbs (Zones III and IV). Aggregate areas are located in Wulukou, Dachaishi, Bell Tower, and Nanshaomen. This zoning pattern is the result of the combined influence of the ancient city layout of Xi'an and the urban development pattern of the 1980s. It not only serves as a significant reflection of urban history and culture but also represents a crucial indicator of urban growth and development.

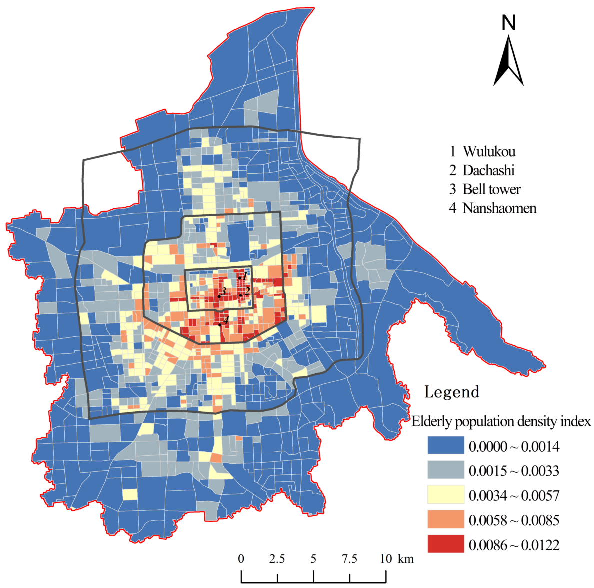

Figure 4. Spatial distribution of the elderly population density index in Xi'an.

The elderly population is concentrated along traffic arteries. Areas with high elderly population densities are primarily distributed in spatial units along the north–south traffic artery and the south second ring road. In the process of expanding built-up urban areas, roads play an important role in communication and connectivity, and the population tends to flow and concentrate in high accessibility blocks.

3.2. Spatial Characteristics of PHC Facilities' Accessibility

There are significant spatial differences in the accessibility of PHC facilities, exhibiting a strongly aggregated pattern (Figure 5). Accessibility in Zones I, II, and III is relatively balanced. However, in Zone IV, it is dominated by low-value areas interspersed with occasional high-value areas, forming a spatial pattern of high and low inlay. The reason for this appears to be that the spatial units with higher accessibility have been greatly influenced by suburban PHC facilities, which have a lower elderly population density compared to the urban core area. The service level available to each person is higher in these areas, which have the same capacity to supply health facilities, whereas the spatial units with lower accessibility seem to be due to the simple shortage of PHC facilities.

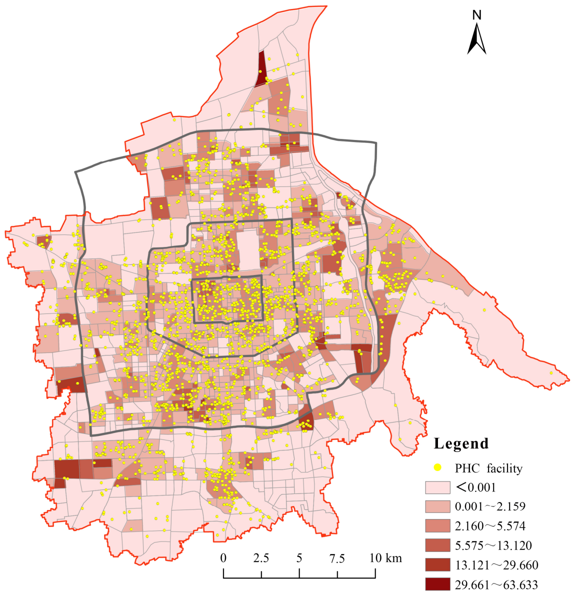

Figure 5. Spatial distribution of accessibility of PHC facilities in Xi'an.

3.3. Spatial Relationship

The spatial bivariate autocorrelation between PHC facility accessibility and the elderly population density index was analyzed using GeoDa software (v1.20). The Moran's I index is 0.157 (Figure 6), with a *p*-value of 0.001 (<0.01) and a z-value of 30.0046 (>2.58). The significance test at the 1% level indicates a significant positive spatial correlation between accessibility and the density index.

The matching result between facility accessibility and the elderly population is heterogeneous, exhibiting a concentric pattern ranging from reasonable allocation (H-H) at the city center to lagging allocation (L-H), advanced allocation (H-L), and then reasonable allocation (L-L) towards the outer areas (Figure 7). There are two distinct levels of matching space. H-H spatial units are mainly distributed in central Zones I and II, with a high degree of fragmentation, mainly because these spatial units are old residential areas of research institutes and state-owned enterprises that have been built since the 1980s. Meanwhile, L-L spatial units are mostly distributed in suburban Zones III and IV, which are relatively concentrated and contiguous. Urban new areas such as Qujiang New Area, Chanba Ecological Area, Xi'an Hi-tech Industrial Development Zone, and Xi'an Economic and Technological Development Zone focus on commerce and business offices, thus attracting a significant number of young individuals.

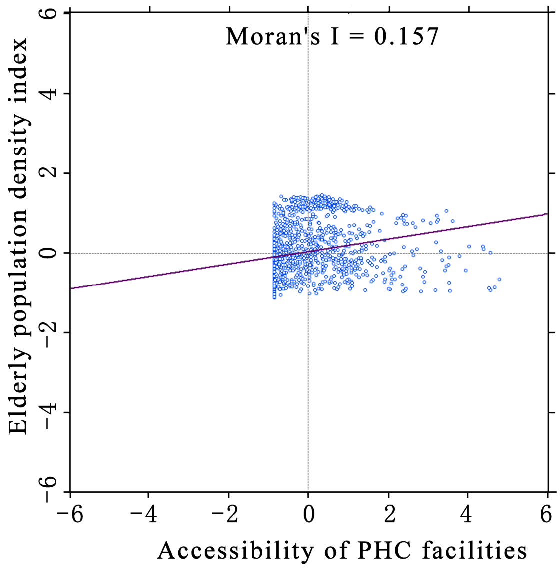

Figure 6. Global autocorrelation diagram between accessibility of PHC facilities and elderly population density index in Xi'an.

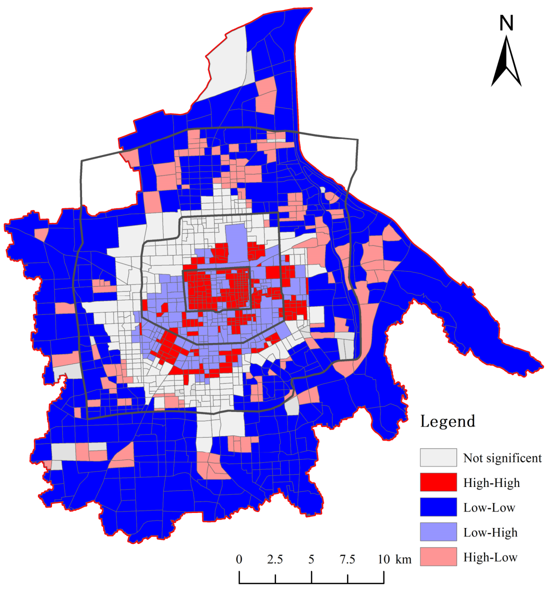

Figure 7. LISA cluster map of PHC accessibility and elderly population density index in Xi'an.

A significant spatial mismatch has been found between accessibility and the elderly population, with varying degrees of mismatch among areas of PHC facilities (Table 3). This mismatch is primarily characterized by a negative relationship between spatial units with lower accessibility and a higher density of the elderly population (L-H). These spatial units are relatively concentrated and continuous, which is related to the increase in the elderly population during urban expansion and the insufficiency of PHC facilities in the context of scarce land. This indicates that existing facilities face challenges in providing equal access to PHC services. Meanwhile, the mismatch between a higher accessibility of medical services and a lower elderly population density in these blocks indicates that elderly residents residing there may have access to a more abundant supply of PHC services, further exacerbating the gap in the equalization of PHC services. H-L spatial units have a high degree of fragmentation, which is related to the construction of the university town. These spatial units have complete PHC facilities but few elderly populations. The number of mismatched spatial units accounts for 27.82% of the total, suggesting that service inequity in all these mismatched spaces needs to be addressed. The spatial mismatch highlights the urgent need for spatial justice and sustainable development.

Table 3. LISA types of PHC facilities accessibility and elderly population in Xi'an.

Spatial Relationship	H-H	L-L	L-H	H-L	None
Number	253	391	205	143	259
Proportion (%)	20.22	31.26	16.39	11.43	20.70

4. Discussion

The accessibility of resources and services is the core of spatial-performance evaluation, and exploring the behavioral needs of the elderly population is crucial to achieving spatial justice in basic health care services and promoting sustainable urban development. The elderly population primarily relies on walking and tends to choose "available" facilities over "closer" ones when accessing PHC facilities. To achieve spatial justice in PHC facilities, it is necessary to eliminate the 'distance threshold' and minimize the travel burden for the elderly population when accessing these facilities, thereby ensuring more convenient access to the required services for all elderly individuals. Furthermore, emphasis should be placed on balancing spatial supply and demand, and a thorough understanding of the spatial preferences of the elderly population regarding PHC services is crucial for ensuring their comfort and satisfaction with these services. This is not only conducive to improving the quality of life for the elderly population but also plays an important role in achieving urban spatial justice and sustainability.

Matched spaces comprise H-H type and L-L type. H-H matching spaces located in central areas have a concentrated elderly population and relatively abundant medical facilities. However, L-L matching spaces in the suburbs have a smaller population, especially for the elderly population, and relatively scarce facilities [44,46,50,51]. Additionally, the number of L-L spatial units is 1.5 times that of H-H spatial units, which is closely related to the expansion model being implemented in the central area with limited land resources and the conversion of large amounts of agricultural land to suburban development. For the H-H match space, despite a certain geographical alignment between the elderly population and PHC facilities, it's crucial to thoroughly consider the elderly population's satisfaction with accessing PHC facilities. Based on the actual situation, it's advisable to either increase the number of PHC facilities or enhance the service level of their facilities and personnel. These strategies can not only prevent a decline in service quality due to overcrowding but also better cater to the needs of the elderly population, thereby improving their quality of life.

Mismatched spaces comprise the L-H type and the H-L type. The L-H type, with an insufficient supply of facilities, manifests in the overuse of existing facilities, resulting in patient detention and prolonged waiting times. Due to differences in economic conditions and demographics, comprehensive public service facilities in the central area (L-H) attract a concentration of the elderly population and a significantly higher aging rate than suburban areas (Figure 8). For the L-H mismatch space, two recommendations are proposed. First, this is to augment the service capacity of existing PHC facilities. This can be achieved by increasing manpower, optimizing equipment configuration, and improving management efficiency, ultimately delivering more accessible and effective medical services to the elderly population. Second, it is recommended to advocate for mixed land use. In order to expand the supply of PHC services, it is necessary to make reasonable use of demolished and vacated land as well as idle and inefficient land, optimize and integrate community spatial resources, and build PHC facilities embedded in the community.

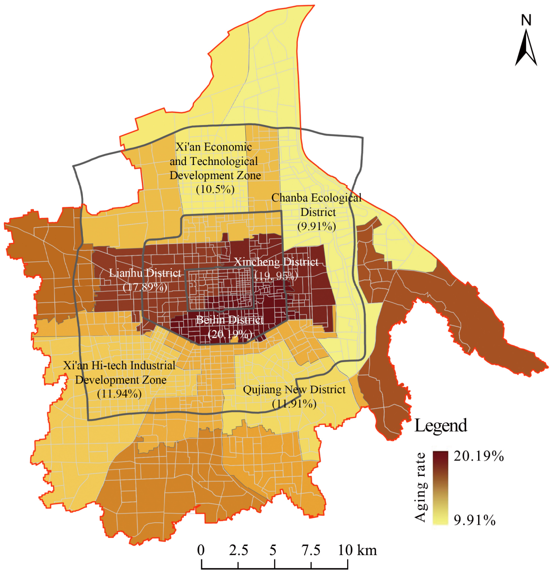

Figure 8. Spatial distribution of aging in Xi'an (district level).

On the contrary, the H-L type, with an overallocation of facilities, manifests unsustainably, resulting in an inefficient use of limited resources [26]. The H-L spatial unit located in suburban areas is formed under a demand for service-oriented development. The reason for this is that the population is relatively small, especially for the elderly population, which leads to unused health care resources. For the H-L mismatch space, our suggestions are as follows: First, dynamically monitor and understand the spatial development trends of the elderly population. Using big data, geographical information systems, and smart-city technologies, we can accurately forecast the evolving patterns in the spatial distribution of the elderly population, thereby supporting the planning and layout of PHC facilities. Second, actively build aging-friendly communities. In accordance with the physical characteristics and needs of the elderly population, it is imperative to actively integrate medical resources from both within and beyond the community, emphasizing the comfort and convenience of PHC facilities. Third, enhancing the accessibility and convenience of PHC facilities is crucial. By optimizing the travel environment, enhancing services, and upgrading the utilization efficiency of PHC facilities, we aim to deliver superior quality and convenient medical and health care services tailored to the elderly population.

This research is innovative in two principal ways. First, the spatial-performance evaluation framework of PHC facilities was constructed from a spatial-justice perspective. It not only focused on facility accessibility, but also paid appropriate attention to the equality and fairness of health care facilities for the elderly population [52]. On the one hand, Ga2SFCA uses a Gaussian function as the distance decay function, considering key factors such as spatial distance attenuation, supply, and demand, allowing for a more accurate measurement of residents' accessibility to public service facilities [15,49,53,54]. The accessibility decay rate of the Gaussian distance decay function exhibits an initial increase followed by a gradual slowdown as the distance increases. This pattern aligns more closely with the demand behavior law of medical services compared to the 2SFCA and E2SFCA models [55,56]. It is believed that the Gaussian distance decay function is well aligned with the principle of proximity to PHC facilities and takes into account spatial asymmetry. The elderly population tends to prefer walking as a mode of transportation when accessing PHC facilities [39], marking a sharp contrast to their tendency to rely more heavily on private cars and public transportation when visiting general hospitals [35]. The daily travel activities of the elderly population are primarily concentrated within a radius of 1000 m (equivalent to a 15 min walk) from their residence, and the proportion of activities within this area reaches as high as 80.9% [57]. This is considered the core area for establishing an aging-friendly spatial system [58]. Therefore, this study establishes a spatial distance threshold of 1000 m, which differs from the community-level spatial distance threshold of 600 m [34]. The evaluation framework based on Ga2SFCA accurately reflects the spatial-distribution differences of PHC facilities and is regarded as the optimal quantitative research method for assessing spatial accessibility [34]. On the other hand, compared with place-based and people-based equality, spatial justice has a greater focus on vulnerable groups. Undoubtedly, the elderly population is a significant constituent of vulnerable groups. The revised population density index based on the elderly proportion of the population places greater emphasis on the concept of spatial justice as a target vulnerable group [52,59]. The framework takes the elderly population, with a greater dependence on PHC facilities, as the target population, and provides a comprehensive and realistic analysis of the spatial-matching relationship between supply and demand.

Second, our study accurately measured spatial performance at the block scale. Spatial scale is a characteristic measure of human insight into the material world. As the basic unit of spatial analysis, urban blocks can provide a targeted reference for urban-refinement management using the Baidu heat map and POI [38,41]. The Baidu heat map relies on the location information of mobile-phone users accessing Baidu products, reflecting the popularity of specific areas through the heat value. When compared to statistical data, the Baidu heat map effectively illustrates the evolving characteristics of population density at the block scale. And POI data not only possess abundant information and precise positioning, but also boast advantages such as affordability and superior real-time performance. Compared to land-use maps and cadastral data, POI data can accurately depict the locational details of geographic entities [46]. The natural block division method aligns more closely with the natural human cognition of urban space compared to the regular grid-division method [35], thereby more accurately reflecting the city's actual situation and yielding more realistic data analysis outcomes. Therefore, using natural blocks as spatial analysis units can more precisely depict the demand for services at the block level. Additionally, compared to macro-levels (such as cities and regions), accessibility analysis at the block scale can reduce potential erroneous information generated in spatial accessibility measurements [36]. The evaluation results are more instructive for optimizing the spatial layout of facilities [1].

Nevertheless, our study was constrained by the available data. To comprehensively evaluate the service capacity of PHC facilities, relying solely on the location information of PHC facilities is not sufficient. While the service capacity of PHC facilities is closely linked to factors such as the building area and the number and level of medical personnel, obtaining these data remains challenging, thus limiting a comprehensive and objective assessment of the service capacity of PHC facilities. Additionally, the travel characteristics and socioeconomic attributes of the population cannot be fully taken into account in the spatial-performance evaluation of public service facilities. The decision making of crowd behavior under spatiotemporal constraints has an important impact on spatial performance.

5. Conclusions

Taking the urban block as the basic spatial analysis unit, we constructed a spatial-performance evaluation model of PHC facilities from a spatial-justice perspective, which is of great significance for achieving sustainable urban development. This study focused on evaluating the spatial-matching association type and distribution characteristics between PHC facilities and the elderly population using the Ga2SFCA method and the bivariate spatial autocorrelation method. The results showed a concentric pattern ranging from reasonable allocation (H-H) at the city center to lagging allocation (L-H), advanced allocation (H-L), and then reasonable allocation (L-L) from the city center towards the outer areas. Facilities in the central area were inadequate due to the excessive gathering of the elderly population, whereas medical services in suburban areas were unsustainable due to poor accessibility. From the perspective of spatial justice, identifying the spatial relationship between facilities and population distribution at the block scale provides guidance for the optimization of PHC layout, which is beneficial for the refined management of cities.

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