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Equity Evaluation of Elderly-Care Institutions Based on Ga2SFCA: The Case Study of Jinan, China

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Abstract: With the deepening trend of aging, the issue of elderly care for the aging population has become a matter of concern for all sectors of society. Elderly-care services have become increasingly vital. Elderly-care institutions, a major component of the elderly-care system, are an important part of public facility resource provision; the spatial distribution of elderly-care institutions (ECIs) directly affects the equitable access of the elderly to public resources. To cope with the current pressure of population aging and limited resources for the elderly, this study aims to explore the relationship between population aging and the supply of ECIs in Jinan, China. Using the ArcGIS platform, this study analyzes the spatial allocation of ECIs, provides improved supply capacity modelling of ECIs based on the Gaussian Two-Step Floating Catchment Area Approach (Ga2SFCA), and evaluates the equity of ECIs in terms of accessibility, supply–demand equity, and spatial equity. The results show that there are large differences in spatial accessibility between different levels of ECIs, there is a mismatch of supply and demand, the number and size of existing ECIs do not meet the needs of the elderly, and the distribution of resources in small ECIs is highly inequitable. These results can provide a guiding direction for optimizing ECIs and urban road network planning and can also provide new insights for urban planners to assess the equity of public service facilities.

Keywords: accessibility; elderly-care institutions; equity; Gini coefficient; spatial distribution; service capacity; Ga2SFCA

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Citation: Jin, M.; Deng, Q.; Wang, S.; Wei, L. Equity Evaluation of Elderly-Care Institutions Based on Ga2SFCA: The Case Study of Jinan, China. *Sustainability* **2023**, *15*, 16943. https://doi.org/10.3390/su152416943

Academic Editor: Mihajlo (Michael) Jakovljevic

Received: 8 October 2023
Revised: 30 November 2023
Accepted: 16 December 2023
Published: 18 December 2023

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1. Introduction

1.1. Background

Population aging is a widespread issue in numerous countries worldwide, and it has become a global demographic trend. The United Nations defined population aging in 1956 as when the number of individuals aged 65 years and above in a country or region surpasses 7% of the total population, indicating that the country or region is entering a phase of aging. When the proportion of people aged 65 years and above in the total population is 14%, the country or region enters a deep aging society [1]. China entered an aging society in 1999, and the trend of aging has further deepened, especially in some mega-cities, where the trend of an aging population is becoming more and more obvious, with one elderly person for every four to five people. According to the National Bureau of Statistics, China's total population at the end of 2021 will be 1412.6 million, and the number of elderly people aged 65 and above will reach 200 million, accounting for 14.2% of the country's total population [2]. This means that China has formally stepped into the stage of deep aging, with a deep aging society coming four years earlier than the predicted time. Population aging reflects, to a certain extent, the progress and development of social civilization, but it also places enormous pressure on socio-economic elements and public health care. According to the Research Report on the Trends of Population Ageing in China, issued by the National Working Committee on Ageing, the population over 80 years of age will account for 12.4 percent of the total elderly population in 2020. At the same time, due to the impact of the baby boom in the early 1960s and 1970s, the proportion is projected to reach 21.8% in 2050 [3,4]. Tens of millions of retirees under the one-child policy will have only one adult child to rely on. This suggests an inverted pyramid for most urban families in China in the future. A couple with only one child will have to take on the responsibility of caring for their own children as well as up to four or more elderly parents. The "four-two-one" family structure will also result in many empty nesters in urgent need of care, most of whom will be disabled elderly individuals dependent on long-term care. It is unlikely that family care will be able to meet the needs of all older individuals, and future generations of older persons may seek alternative forms of elder care beyond their homes. Elderly-care Institutions (ECIs) are one such option [5]. Institutional elderly-care services play an increasingly important role in addressing the frailty and illness of older individuals.

Data from the 11th Five-Year Plan for the Development of the Elderly in China shows that, on average, one-quarter of China's elderly population over the age of 60 experiences impaired muscular functioning and requires varying degrees of nursing care. Currently, long-term care for the elderly is a field riddled with contradictions, and the increasing cost of medical care poses a significant financial strain on the government and places a heavy economic burden on families [6]. The highlighting of these contradictions means that people will face the dilemma of a declining quality of life due to the lack of care for the elderly. This results in long-term care becoming an "unbearable weight of life" for many elderly people and becoming a new social risk. While the growing elderly population puts pressure on society and families, it also creates a significant demand for elderly-care facilities. If these institutions are configured to meet the specific type and level of need, more elderly individuals will be able to access the necessary services in their local communities. At the same time, ensuring the well-being of the elderly necessitates the implementation of equitable safeguard mechanisms and fair decision-making methods. These measures are crucial in guaranteeing the equitable distribution of benefits and costs in society, and they also play a significant role in achieving sustainable social development [7,8]. Therefore, the importance of ECIs cannot be ignored, especially because long-term care is desirable and even necessary for a portion of the elderly population due to various issues, such as poor health, disability, living alone, and empty nesters [9,10].

In 2007, the World Health Organization (WHO) introduced a framework for constructing age-friendly cities and communities, urging countries to consider the environmental aspects of age-friendly cities and create urban environments that promote the health and well-being of elderly individuals while eliminating barriers to their participation in family, community, and social life. The Global Guide to Aging Cities and the accompanying Inventory of Essential Characteristics of Aging Cities [11] were developed as a significant initiative to shift the focus of urban planning towards the aging population. Transforming Our World: 2030 Agenda for Sustainable Development [12], unanimously adopted by all United Nations member states in 2015, prioritizes equality and equity and emphasizes the needs of vulnerable populations. The text discusses the importance of promoting healthy lifestyles, ensuring the well-being of people of all ages, and reducing inequality within and between countries. It also proposes new development goals in these areas to ensure a world that is just, equitable, tolerant, open, socially inclusive, and able to meet the needs of vulnerable groups. Elderly people are among the vulnerable groups in society. In 2022, China's National Development and Reform Commission formulated a program development requirement to improve the level of equalization of basic public services [13]. In the face of this common requirement, the degree of equity in the distribution of resources for public services, especially for elderly-care services, has become a pressing concern within and between countries.

In the face of the pressure of rapid population growth and limited spatial resources, it is crucial to optimize existing facilities and rationally allocate additional facilities in existing communities. In urban planning, equity is considered a controversial issue in the distribution of public services [8]. As one of the most crucial issues related to the sustainable development of society, the objective of equity in urban planning is to fulfill the needs of specific groups by ensuring the potential accessibility of facilities. This, in turn, guarantees a fair distribution of resources and reduces inequality in society [14]. Elderly-care facilities are not only an important public resource in the city but also a basic societal need that is increasing day by day. However, the construction of these facilities is not keeping pace with the speed of aging. The current development of elderly-care facilities in China is primarily characterized by a limited number of ECIs, low quality of ECIs, slow progress in the development of ECIs, and a mismatch between supply and demand [15]. The imbalance between the needs of older persons and the resources provided by society cannot be ignored. To ensure fair and equitable access to public resources for the aging population, it is necessary to assess the spatial accessibility and equity of ECIs. This will help to identify an optimization strategy to improve the layout of existing ECIs and ensure that older people have equal and fair access to these facilities, thereby improving their quality of life. The prerequisite for achieving equity in the distribution of facilities is to align the supply of facilities with the demand of the population. This involves not only balancing the number of people and the availability of public resources but also ensuring that the distribution of public resources aligns with the spatial distribution of the population.

1.2. Literature Review

Equity is a central concern in all fields, and approaching fairness and equity in distribution of urban public facilities is an important goal for urban planners [16]. Equity in the distribution of public facilities means that citizens have equal access to an equal distribution of public resources, based on a balance of quantity and spatial matching [17]. Theoretically, spatial equity stems from social equity [18]. Spatial equity is concerned with differences in the level of spatial distribution of facilities; social equity and justice is concerned with equal access to public resources for citizens of different groups, regions and needs. Several scholars have evaluated the equity of the spatial distribution of public service facilities using different methodologies [19,20]. Distributional equity is usually evaluated in terms of accessibility to the extent of available resources [21]. Equity assessment is conducted in terms of a match between population and resources [22]. The research results of quantitative analyses combining accessibility and equity have focused on public service facilities such as public green spaces [23–26], transport facilities [27], and healthcare organizations [28–30], providing a comparison of the spatial distribution of different socio-economic groups in relation to public facilities and services to see whether these inequalities contribute to the socio-economic deprivation of the population [31]. As the elderly-care institution (ECI) system is in the initial development stage, there are fewer studies on ECIs. Research on ECIs and aging is mostly focused on the spatial distribution and construction of the facility system, accessory standards, configuration rationality [32,33], traffic organization, optimization of the layout of the facilities [34], etc., and most studies use qualitative analysis, questionnaire surveys, field surveys, and subjective evaluation methods to carry out their research [35,36]. This results in greater attention being paid to the impact of the demand at an architectural level and quantitative analysis of the research at the urban level. There is a relative lack of quantitative analysis at the city level, and few scholars have explored the issue of spatial allocation equity of elderly facilities at the city level in the context of urban spatial accessibility, supply–demand equity, and geographical parity.

Accessibility is an important indicator for evaluating spatial equity in public facilities, and it is also the basic goal of healthcare service provision in many developed countries [11]. Accessibility estimates how easily a person can reach a potential destination [29]. It is an effective measure of service capacity that helps urban planners identify areas where public services are scarce [16]. It focuses on various inter-facility factors to reflect accessibility in relation to service areas, transportation distances, and time costs [27,37]. In recent years, the focus of accessibility has gradually shifted from macro to micro and from spatial efficiency to spatial equity [38–41], and the concept has been widely applied to the study of the spatial layout of urban public service facilities. Commonly used analytical methods include the buffer zone method [42,43], potential model [44], shortest distance method [16,45], Huff model [46], gravitational modeling method [38], and two-step floating catchment area method (2SFCA) [29,30,34,37,39], among others. Among these methods, the 2SFCA and potential model have been found to have fewer errors in their calculation results and are more widely utilized. The 2SFCA considers various influencing factors, including the scale of supply and demand, the distance of the actual road network, and more. It also considers distance attenuation, travel mode, time cost, and search thresholds. Based on comprehensibility and operationalization, 2SFCA is one of the most popular accessibility measures. It can be used to define accessibility calculations within a region. The 2SFCA method is well known for its use in health service planning in developed countries [47–49], and it has also been explored in developing countries [50]. Typically, three factors are critical to measuring the spatial accessibility of public facilities resources: facility supply capacity, the number of people served, and geographic impediments between points of supply and demand [40]. The supply capacity of public facilities and the number of people served are primarily considered in the context of supply and demand equity. Geographic impedance is the opportunity or cost paid by residents to travel to public facilities, which is usually expressed using travel time or geographic distance. The OD cost matrix is one of the most popular expressions of geographic impedance [51,52], and some researchers have calculated the travel time of residents driving to essential services based on the origin-destination time cost matrix and GIS road network analysis [53].

Spatial equity in the distribution of public facilities can be considered on the basis of a combination of two perspectives, with both involving minimum standards [54]. This suggests that the level of minimum provision should be sufficient to ensure that all individuals have the same minimum choices, even if it is only for a range of services to satisfy their basic needs [54]; and that on this basis and composition, the allocation should begin; if there is a surplus to be allocated, it should be allocated to areas of lesser 'enjoyment' [54]. The Gini coefficient was originally used to characterize the income distribution of a population and is an important indicator of the relationship between the actual distribution and the average distribution [55]. Some researchers constructed a fairness evaluation model by combining accessibility and the Gini coefficient, and analyzed the balance and equity of the distribution of public facilities in terms of spatial equity and social equity [45,56–58]. The Gini coefficient mainly studies the gap in resource distribution, which is more reflected in social equity, and some scholars [41,57,58] have used the "accessibility-Gini index" system to evaluate the fairness of the facility layout. In addition, the locational entropy method, which identifies the specific pattern of spatial matching between the layout of facilities and the distribution of the population, has also been used to measure the fairness of public service facilities [59,60].

The main objective of this study is to determine the fairness of the spatial distribution of multi-tier ECIs by building a model for fairness evaluation and providing a method for combined spatial accessibility and fairness analysis, i.e., Ga2SFCA. This provides a reference for optimizing the layout of ECIs. Although there are many researchers using 2SFCA to analyze the accessibility and fairness of elderly-care facilities, existing studies on the fairness of ECIs often focus on a certain level of facility regarding the selection of the object [61,62], which does reflect the Chinese multi-tiered elderly-care facility system. The analysis of multilevel elderly-care facilities also fails to address the comparative study of multilevel accessibility [34,39]; thus, it is necessary to study the evaluation of multilevel elderly-care facility accessibility and equity. We conducted a case study of the equity evaluation of hierarchical ECIs in the central city of Jinan, China. The findings are of theoretical and practical significance for alleviating the problem of aging, meeting the needs of the population in old age, promoting the equitable allocation of resources for the elderly, and realizing the equalization of basic public services. An easily replicable method is provided for urban planners to assess and compare the impact of facility allocation on equity.

1.3. Study Framework

This study takes the central urban area of Jinan City as an example, with the help of ArcGIS (version. 10.5), and adopts the Gaussian Two-Step Floating Catchment Area (Ga2SFCA) method, using the geometric center of subdistricts as demand points and the existing ECIs as supply points. We constructed OD cost matrices based on actual travel times at supply and demand points and travel speeds at all levels of the network using the network analysis tool in the ArcGIS platform [16,45]. We focused on the assessment of the accessibility of the elderly institutions in Jinan City, combining the Gini coefficient, Lorenz curve [41,57], and location entropy to comprehensively evaluate the fairness and reasonableness of the spatial distribution of ECIs in Jinan. The usability of the methodology is verified through case studies, and the conclusions can provide a scientific basis and decision-making reference for the adjustment and optimization of ECI distribution. As shown in Figure 1, the steps of the research framework of this paper are as follows: first we preprocess the data and then build a database using ArcGIS, and second, we evaluate the equity of ECIs through a multi-step study. The specific steps are as follows. In the first step, the ECIs are categorized into three levels based on the evaluation of their service capacity. In the second step, the spatial distribution of the elderly population and ECIs is analyzed and presented visually. In the third step, the accessibility of the graded ECIs is analyzed using the Ga2SFCA method. In the fourth step, the spatial equity of the ECIs is analyzed using the Lorenz curve and the Gini coefficient. In the fifth step, the per capita accessibility of resources in the graded ECIs is evaluated using the locational entropy method. Finally, the reasons for the differences between accessibility and equity as well as optimization strategies are discussed.

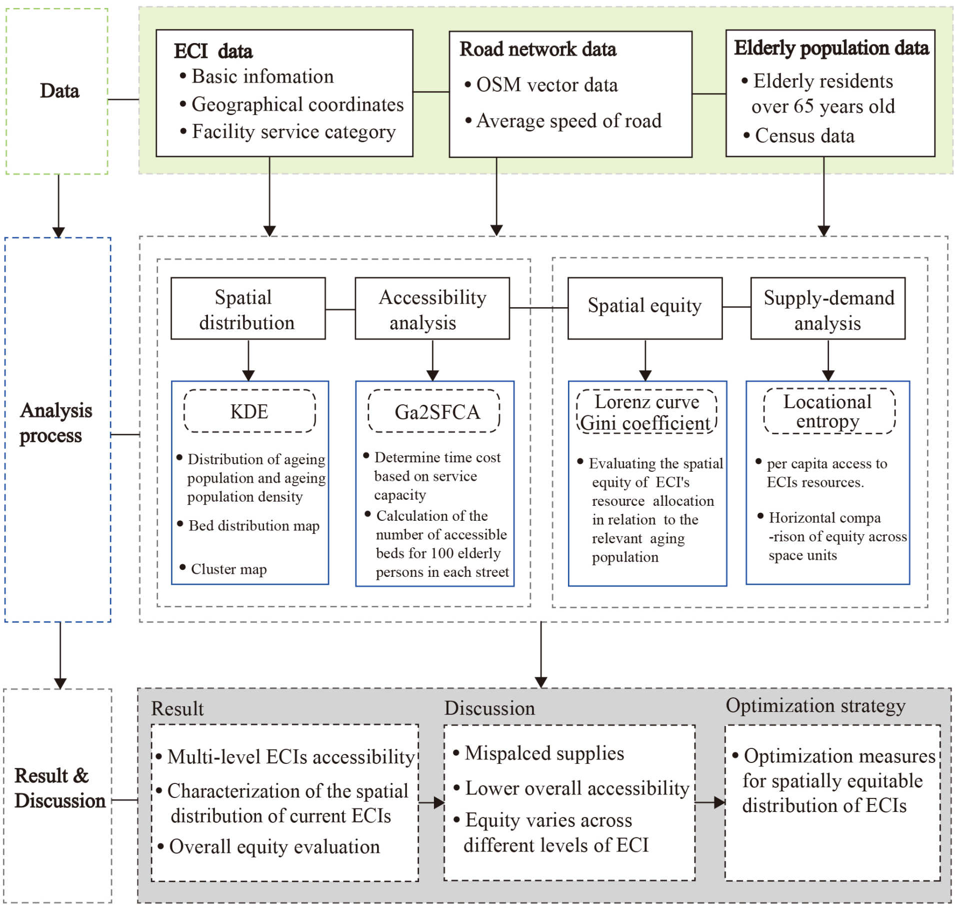


Figure 1. Study framework.

2. Data and Methods

2.1. Study Area

Jinan is the capital of Shandong Province and the central city in the southern region of China's Bohai Rim [62]. After experiencing rapid development since the reform and opening in the 1980s, Jinan has transformed into a mega-city, with a resident population exceeding 9 million. It is comprised of 10 districts and 2 counties under its jurisdiction. According to the Jinan Urban Master Plan (2011–2020), the city's towns and cities are divided into four levels: central cities, sub-central cities, central towns, and general towns. These include one central city (Jinan Central City), four sub-central cities, 16 central towns, and 30 general towns. Public service facilities in urban and rural areas are allocated according to the four levels, and a social service network system covering the entire city is being built. The central city is in the suitable construction area between the Yellow River in the north and the mountainous area in the south, and the planning scope extends eastward to the urban boundary and southwestward to the Changqing District. In 2020, the urban construction land area of the central city was 410 square kilometers (including Tianqiao, Shizhong, Huaiyin, Lixia, Lixing, and Changqing Districts), and the per capita construction land area was 95 square meters. The location and scope of the central city are shown in Figure 2.

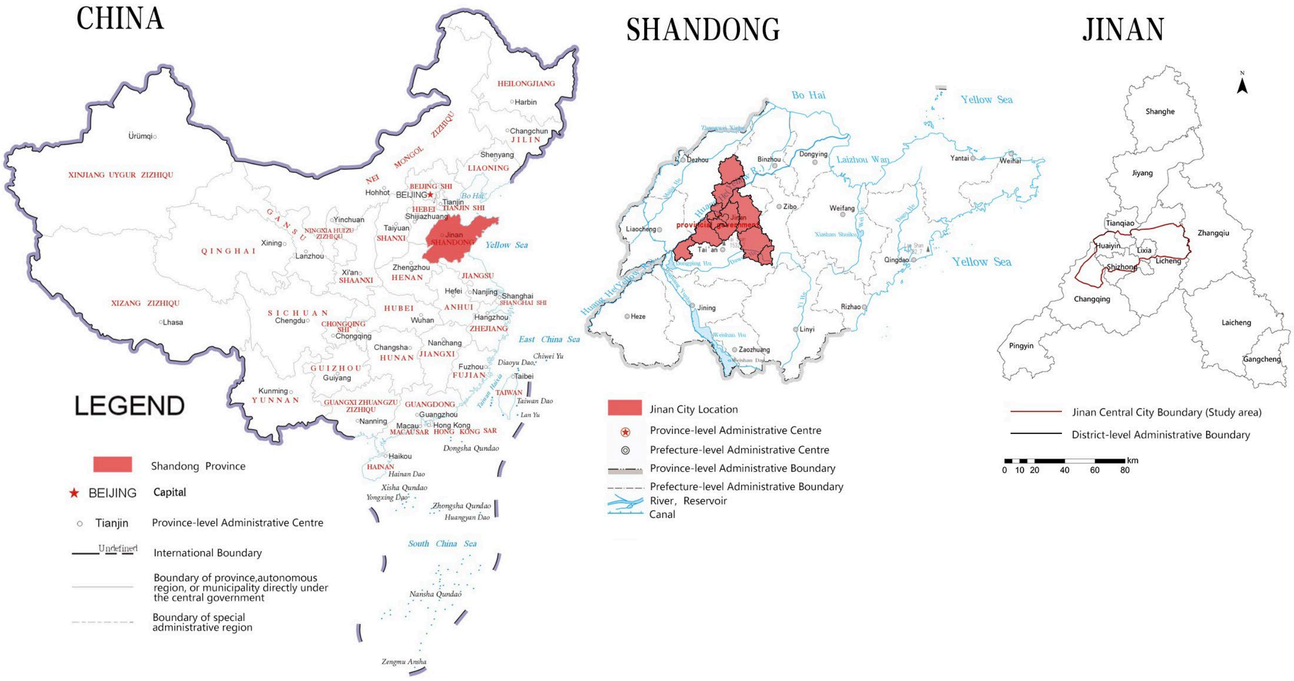


Figure 2. Jinan city center location (study area).

Compared with the suburbs and rural areas, the central city has a high concentration of building land and started development earlier. In terms of construction, the public service facilities in the central city are more complete, and the road network is more continuous; in terms of population, the central city has the characteristics of a large population base, rapid growth, and an aging population. Relatively speaking, the demand for facilities for the elderly is larger, which makes it representative for exploring the service level of urban elderly institutions. As the highest level of the four tiers of the central city, its public service facilities configuration standard is the highest. The central city of Jinan is selected as the study area, which contains a total of 81 streets and townships, and based on data availability, 81 streets are used as the study unit. The relatively high demand for ECIs in the central city is representative for exploring the equity level of ECIs in urban areas. As the highest level among the four levels, the central city has the highest standard of public service facilities allocation. The central city of Jinan is selected as the study area, which contains a total of 81 subdistricts and townships. Based on the availability of data, this paper selects 81 subdistricts (the subdistrict level is set as the smallest spatial scale studied in this paper) in the central urban area of Jinan City as the research sample.

2.2. Data Sources and Processing

The main data and information needed for this study include the following: (1) data on the administrative boundaries and subdistrict boundaries of the central urban area of Jinan; (2) data on the spatial location of elderly institutions in the central urban area of Jinan; (3) data on the spatial distribution of the elderly population; (4) the road network data of Jinan City. All data are in the WGS-1984 geographic coordinate system.

2.2.1. Elderly Population

The demographic data used in this paper come from the Seventh National Population Census 2020 Shandong Province Population Census Yearbook (shandong.gov.cn). The population data selected for this study are the elderly resident population aged 65 and above, the center of the subdistrict is considered as the basic demand point of the population, and the administrative boundary line of the subdistrict is from the China Geographic Information Resources Catalogue.

According to data from the Jinan Seventh National Population Census Bulletin, Jinan has a household population of 1,837,100 elderly people aged 60 years and over, accounting for 19.96 per cent of the city's total population, of which 1,295,000 are aged 65 years and over, accounting for 14.07 per cent of the total population, an increase of 4.76 per cent from 2010. According to Table 1, by the end of 2020 in Jinan City, the Lixing District had the highest proportion of resident population, reaching 12.08%; the Laiwu District had the highest aging rate, reaching 18.96%; the Changqing District within the central city of Jinan had the highest rate of deep aging, at 14.17%; and the Lixing District had the lowest rate of deep aging, at 10.11%. In the city, most of the areas with deep aging rates higher than the Jinan average are remote rural areas and townships, while the areas with lower aging rates are urban areas with better economic development; this is due to the imbalance in development between urban and rural areas, with more young people choosing to live in the urban areas with better economic development.

Table 1. Basic information on the resident population and the elderly population in the city and its districts (functional areas).

Region	Resident Population	Share of the City's Resident Population (%)	Number of Residents Aged 65 and Over	Regional Deep Aging Rates (%)
Citywide	9,202,432	100.00	1,294,977	14.07
Lixia Area	819,139	8.90	100,724	12.30
Shizhong Area	903,714	9.82	114,864	12.71
Huaiyin Area	675,048	7.34	76,370	11.31
Tianqiao Area	718,024	7.80	91,802	12.79
Licheng Area	1,112,022	12.08	112,372	10.11
Changqing Area	595,549	6.47	84,365	14.17
Zhangqiu Area	1,075,784	11.69	178,729	16.61
Jiyang Area	401,826	4.37	66,756	16.61
Laiwu Area	816,009	8.87	154,677	18.96
Gangcheng Area	286,966	3.12	47,888	16.69
Pingyin Area	323,072	3.51	58,434	18.09
Shanghe Area	527,311	5.73	95,473	18.11
Gaoxin Area of Jinan	424,047	4.61	38,646	9.11
Gaoxin Area of Laiwu	153,623	1.67	13,965	9.09
Pioneer Area	166,031	1.80	27,228	16.40
Southern mountains	204,267	2.22	32,682	16.00

2.2.2. Elderly-Care Institutions

In recent years, the Chinese Government has been working to establish a well-organized grading system for ECIs. However, the varying service capacities of ECIs and the diversity of service types tend to lead to inconsistent grading standards. Considering these issues, the priority for measuring the spatial equity of ECIs is to determine appropriate grading criteria to grade ECIs. While the service capacity of ECIs is related to a variety of factors, the Planning Code for Urban Elderly Facilities [63] has put forward appropriate requirements for the number of beds and floor area of ECIs. Elderly-care institutions are categorized into three size levels, namely small, medium, and large, according to the number of beds, floor area, service recipients, and service content (Table 2).

Table 2. Service capacity evaluation indicators for multilevel ECIs.

Multilevel ECIs	Number of Beds	Service Recipients	Basic Service Content
Small ECIs	<100 beds	self-care elderly; device-aided elderly	Meal provision, personal care, health rehabilitation, recreation, and transportation services
Medium-sized ECIs	100~300 beds	self-care elderly; device-aided elderly; nursing-cared elderly	Daily living, food service, health care, culture and entertainment services
Large ECIs	>300 beds	device-aided elderly; nursing-cared elderly	Life care, food service, medical care, rehabilitation and recreation, psychological counseling, hospice care, and other services

The ECI data used in this study mainly come from the "Gaode Map API" website (lbs.amap.com., accessed on 5 March 2022), an open platform that can extract point-of-interest (POI) data in bulk (as of May 2022) by inputting the names of categories of institutions such as nursing homes, day-care centers, and care service centers as keywords. The data mainly includes information such as the name of the institution, location, and geographic coordinates, which is calibrated with the elderly care data published in the explicit information of the Jinan public data open platform; the corresponding bed data, etc., are added (data as of August 2022). The bed statistics of hierarchical institutions are shown in Figure 3.

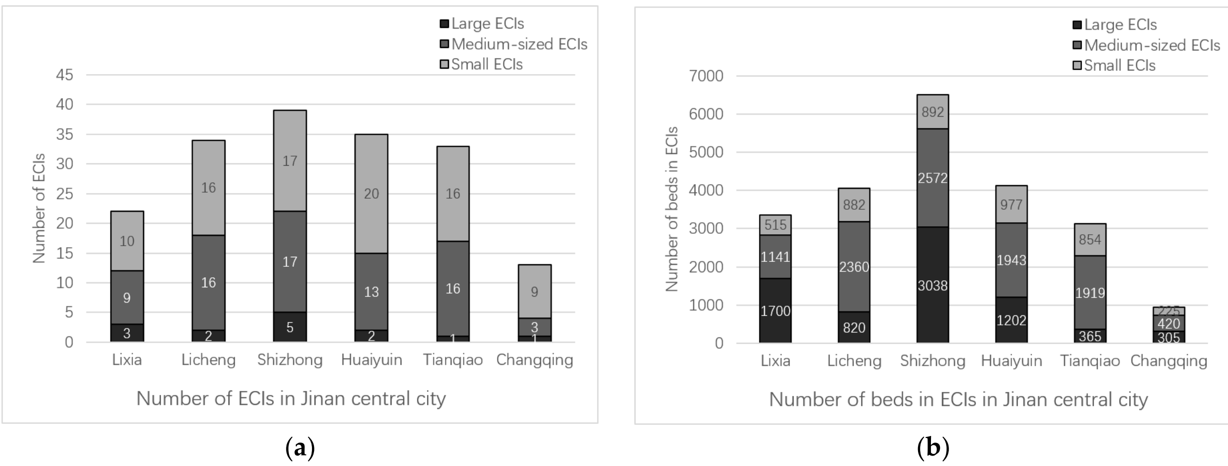


Figure 3. (**a**) Number of ECIs in Jinan central city. (**b**) Number of beds in ECIs in Jinan central city.

Other information, including facility type, number of beds, floor area, service content, and fees, was obtained from websites such as the official website of elderly-care institutions and the Elderly Care Information Network (https://www.yanglaocn.com/) (data as of

November 2022). After further verification and deletion of duplicates, the final data of 176 ECIs were obtained.

2.2.3. Road Network Data

The road network data were obtained from OpenStreetMap (OSM). In the case study, we use distances based on the actual road network as the cost of travel [16]. Using the ArcMap (version. 10.5) tool Network Analyst, we assumed that the driving route was the shortest route and set the speed of the car using the speed limit of each road [45]. The road network is divided into four classes: urban expressway, main road, secondary road, and branch road. Speed attributes are assigned to each class of road. According to the Urban Road Engineering Design Code [64] and previous studies [65,66], the travel speed is determined based on the standards specified in the urban road grade. The road grade and speed distribution are outlined in Table 3. We converted the road network into vector data and created the road network dataset.

Table 3. Average speed on four classes of urban roads.

Road Classification	1	2	3	4
Road types	urban expressway	main road	secondary road	branch road
Speed(km/h)	50	40	30	20

2.3. Equity Research Framework

It is common practice to consider population to represent a demand for the number and type of services in an area [17,21] and public facilities as the supply, and to consider opportunities in conjunction with the service capacity of the supply. The OD cost matrix is the cost of travelling from the facility site to the residential site (distance, travel time, or travel cost) [16]. The accessibility concept was used for measuring the cost of travel between locations of demands and supplies. The equity research framework is as follows.

Firstly, the spatial distribution characteristics of the population and ECIs in Jinan City are analyzed based on the subdistrict scale; then, the accessibility levels of three grades of ECIs are measured based on the Gaussian two-step moving search method according to the time cost of the taxi mode. The spatial equity of ECIs is analyzed by using Lorentz curves and Gini coefficients, and the per capita accessibility of graded ECIs is evaluated by using the location entropy method. Finally, the distribution characteristics and differences of the accessibility and fairness levels of elderly institutions are analyzed. The supply and demand balance of ECIs in Jinan is analyzed (Figure 4).

2.4. Methodology

2.4.1. Kernel Density Estimate Method (KDE)

Kernel density analysis is the most commonly used method to study the distribution characteristics of geographic elements in a certain area by calculating the spatial location of point elements to show the spatial layout characteristics of the point elements and clustering conditions. This method can be more intuitive in analyzing and expressing some of the larger and difficult-to-respond-to characteristics of the spatial layout of the distribution of the trend of the discrete point data [67]. In this paper, the kernel density estimation method is applied in the study area to analyze the clustering characteristics of all ECIs in the spatial distribution of the city, which is calculated by the following formula:

$$f(x) = \frac{1}{nh}\sum_{i=1}^{n} k\left(\frac{x - x_i}{h}\right) \quad (1)$$

where $f(x)$ is the kernel density estimate of the distribution of pension facilities in the study area, k is the kernel function, i represents the individual districts in the study area, h is the bandwidth (i.e., the search radius of the kernel density function), n is the total number of POIs, and $x - x_i$ is the distance from the point x to the sample x_i.

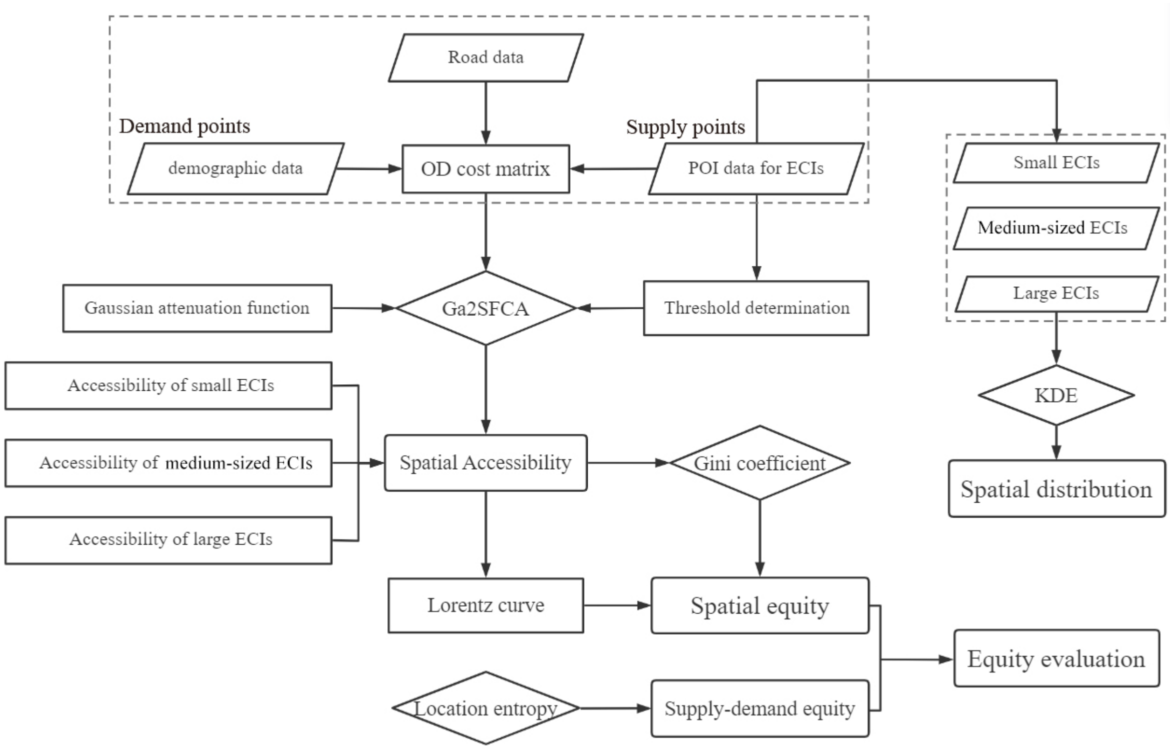


Figure 4. Technical flow chart.

2.4.2. Two-Step Floating Catchment Area Method (2SFCA)

The two-step floating catchment area method (2SFCA) was first proposed by John Radke and Lan Mu et al. (2000) and was further improved by Wei Luo et al. (2003) and named 2SFCA [47]. It has been widely used by scholars in the accessibility measurement of various kinds of public service facilities, such as urban green space [23,25,26,58,59], elderly-care facilities [34,35,39,50,60,61,64,65], and healthcare facilities [19,20,28–32,41,44,48]. The 2SFCA method centers the search on the supply point and demand point, sets a travel limit distance or time as the search radius (i.e., distance threshold), and compares the number of resources or facilities that can be approached by the residents within the two search thresholds; the higher the value, the better the accessibility. In this paper, the geometric centers of subdistricts are the demand points, and the existing ECIs are the supply points. The calculation formula and steps are as follows:

In the first step, for each ECI j, given a spatial distance threshold d_0, for the population of each subdistrict k in spatial unit, an attenuation function is introduced; common attenuation functions include constant, linear, exponential, power, and Gaussian attenuation functions. In this paper, using the vehicular road network dataset, based on the cost of travel time, it is determined that the use of Gaussian function $G_{d_{ij}}$ to assign weights and summing these weighted populations will yield the number of all potential users of ECI j; the supply–demand ratio R_j is then calculated.

$$G(d_{ij}) = \frac{e^{-0.5\times\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-0.5}}{1 - e^{-0.5}} \ (d_{ij} \le d_0) \tag{2}$$

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj\le d_0}\}} G_{(d_{ij})} P_k} \tag{3}$$

where p_k is the number of elderly people in subdistrict k (i.e., $d_{kj} \leq d_0$) in the search area; S_j is the total supply at point j; and d_{kj} is the distance of the road network between locations k and j. R_j is the supply–demand ratio for point j, and $G(d_{ij})$ is the distance attenuation function within the search range.

In the second step, for each elderly population distribution point i, given a spatial distance threshold d_0, a spatial demand range is formed; d_{ij} is the distance between the demand point i and the supply point j. Each ECI supply/demand ratio R_j falling within the spatial demand range is assigned with a weight by utilizing the Gaussian attenuation function; then, the weighted supply–demand R_j is summed, and the accessibility to elderly-care services at each distribution point of the elderly population is obtained. A_i denotes the accessibility of the demand point *i*.

$$A_i = \sum_{j \in \{d_{ij \leq d_0}\}} G_{(d_{ij})} R_j \tag{4}$$

2.4.3. Lorenz Curve, Gini Coefficient, and Location Entropy

The Gini coefficient and the Lorenz curve are commonly used in economics to evaluate the differences in income distribution in a country or region. Due to the similarity of the social equity connotation of income distribution and public resource distribution, this method is commonly used by scholars to evaluate the equity and justice performance of the level of service of public facilities, such as public transportation, healthcare facilities, public green spaces, and elderly-care facilities [45,55–58]; therefore, the Gini coefficient and the Lorenz curve are introduced to reflect the degree of match between the resources of ECIs and the population. The degree of equality in the distribution of resources for elderly-care facilities is judged according to the interval of the Gini coefficient; the Lorenz curve uses a graphical representation of the distribution of resources for elderly-care facilities among the elderly population, which allows for an analysis of the proportion of elderly-care facilities enjoyed by the elderly population in different population proportions [68,69]. The ECI accessibility values for each subdistrict were ranked to obtain the cumulative elderly population to plot the Lorenz curve. The Gini coefficient can be expressed as follows:

$$G = \frac{S_1}{S_1 + S_2} = 1 - 2S_2 \tag{5}$$

where G is the Gini coefficient, which ranges from 0 to 1. The larger the value, the higher the inequality in the region. The smaller the value, the more equitable the region. From the Lorenz curve, 2 $(S_1 + S_2)$ = 1, so only S_2 can be calculated. The formula is as follows:

$$S_2 = 0.5 \sum_{i=1}^{n} (W_{i+1} + W_i)(P_{i+1} - P_i) \tag{6}$$

where W_i is the cumulative percentage of accessibility and P_i is the cumulative percentage of population.

The Lorenz curve and the Gini coefficient can measure the equity of ECIs in general, but they cannot reflect the specific pattern of spatial matching between the layout of ECIs and the distribution of the elderly population [70]. Thus, the concept of locational entropy is introduced to quantitatively evaluate the match between the resources and the population of each spatial unit [59,60], as shown in Equation (7).

$$LQ_j = \left(T_j \,/ P_j\right) / (T/P) \tag{7}$$

where LQ_j is the location entropy of spatial unit j; T_j and T are the number of ECI resources in spatial unit j and the total study area, respectively; and P_j and P are the number of elderly populations in spatial unit j and the total study area, respectively.

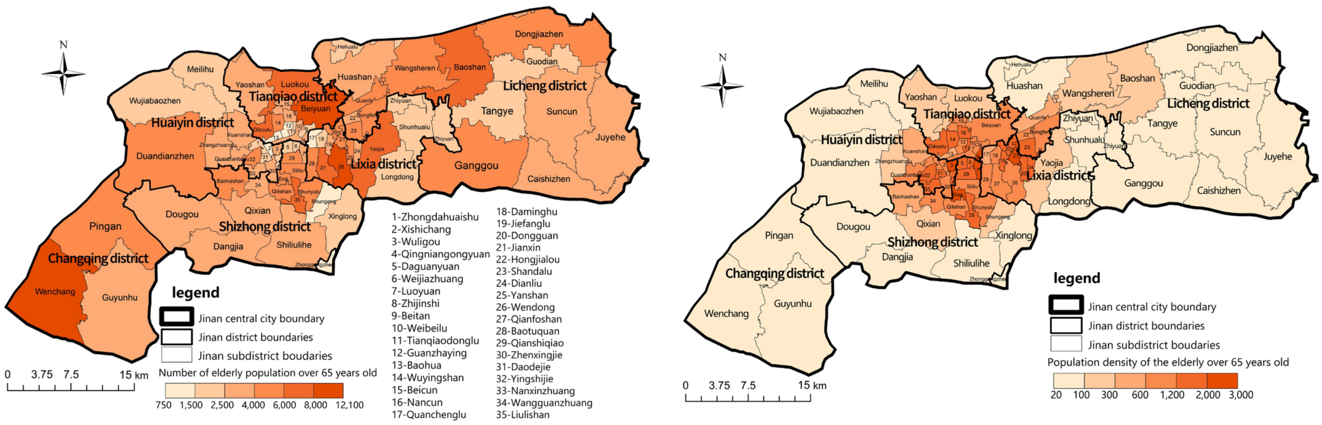
3. Results

3.1. Spatial Distribution of Population and ECIs

3.1.1. Spatial Distribution of the Elderly Population

By organizing the statistical data, the number of elderly people over 65 and population density distribution map are drawn by visualizing the index in ArcGIS, grouped into six different classes based on the Jenks natural breaks classification method. This natural breakpoint classification method is a statistical method that grades and classifies values according to the laws of numerical statistical distribution. The darker the color, the higher the population or population density. The lighter the color, the lower the population or population density.

The visualization results show that the elderly population in the central city presents a spatial distribution pattern of dense center and sparse periphery. It is mainly concentrated in the four districts of Lixia, Shizhong, Huaiyin, and Tianqiao (Figure 5b). Some of the subdistricts in the center have high population density and small subdistrict administrative scope, while the suburbs have lower construction density, low population density, and generally larger subdistrict scope. Jinan central city shows an elderly population density from the inside out with a high to low circle spatial distribution pattern; on the subdistrict scale, the average number of resident elderly in the subdistricts is 3780; the lowest number of elderly in a subdistrict is in the Baohua subdistrict, at 744 people; the largest number in a subdistrict is the Beiyuan subdistrict, at 12,063 people; the Jinshi, Erqi, and LuoYuan subdistricts have a higher elderly population density, and the Dangjia, Xinglong, Diaoqiaozhen, and Caishizhen subdistricts have lower elderly population density (Figure 5a).



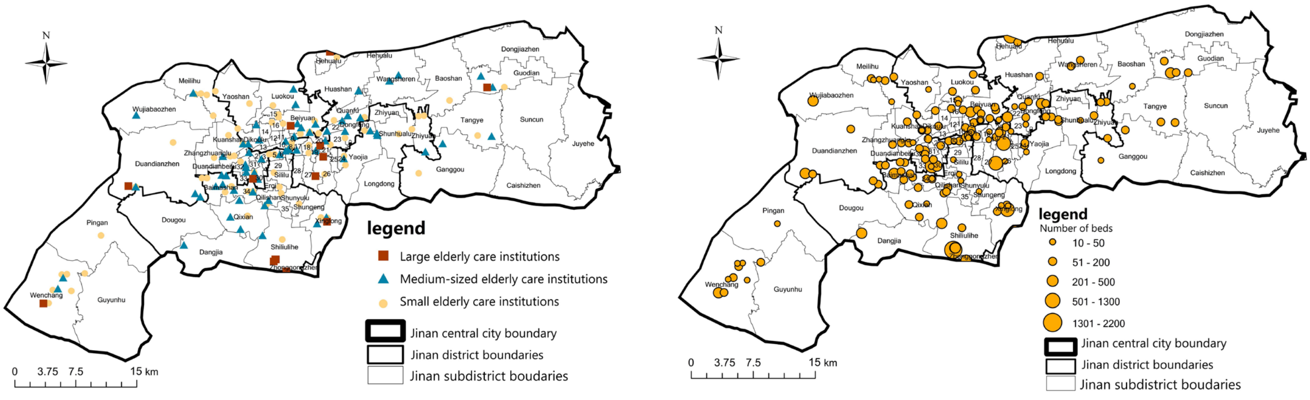
(**a**) (**b**)

Figure 5. (**a**) Distribution of the population aged over 65 in the subdistrict; (**b**) distribution of density of elderly population over 65 years old in the subdistrict.

3.1.2. Spatial Distribution of Elderly-Care Institutions

There are 176 ECIs in the study area, the spatial distribution of which was visualized using ArcGIS (Figure 6a). There are 22,237 beds in the area, with an average of about 34.9 beds per 1000 elderly people. The size of individual institutions varies greatly, ranging from a maximum of thousands of beds to a minimum of only a dozen beds (Figure 6b). By 2020, China will have an average of 31.1 beds per 1000 elderly people, which is a big gap compared to the level of 50–70 beds in developed countries. According to the "14th Five-Year Plan", for every 1000 elderly people in China, there should be 35 to 40 beds. Jinan Municipal People's Government issued the Opinions on Accelerating the Development of the Elderly Care Service Industry (hereinafter referred to as Opinion) [71], which pointed out that the construction goal to achieved by 2020 is at least 40 beds available per 1000 elderly people in the city area, i.e., 4 beds per 100 elderly people. According to the Jinan Municipal Government, 4 beds per 100 people is used as a standard to measure whether the resource allocation of ECIs in the subdistricts of the central city has met the requirements.

The current number of beds in institutional care within the study area fails to meet the number of beds per 1000 elderly citizens as required by the Opinion.



(**a**) (**b**)

Figure 6. (**a**) Spatial distribution of multilevel ECIs; (**b**) distribution of beds in elderly-care institutions.

The spatial hotspot distribution pattern of ECI was analyzed in ArcGIS (10.5) using kernel density estimation, and the overall spatial distribution of ECIs showed an uneven state, with two distinct agglomerations in the central part and several smaller hotspot areas. The areas with the highest kernel density values are near the junction of the four administrative districts in the city center, clustered in 8—Zhijinshi, 9—Beitan, 10—Weibeilu and 17—Quanchenglu, which are in the form of multi-core agglomerations and are connected in slices along the east–west direction; the areas with sub-high kernel density values are located in the areas of 31—Daodejie and 33—Nanxinzhuang subdistricts. Nanxinzhuang subdistrict is the center, with the periphery spreading out to form Wenchang, Meilihu, Shiliulihe, and Xinglong subdistricts as the center of small hotspots; the kernel density in the eastern and western parts of the central city shows a small number of scattered distributions and does not form an agglomeration; in addition, there are parts of the subdistricts that are not covered with ECIs, e.g., Guyunhu, Dougou, Longdong, Suncun, Dongjiazhen, Caishizhen, and Juyehe subdistricts. Specifically, the agglomeration area in the Lixia District, Shizhong District, Huaiyin District, and Tianqiao District, forming a junction of the part of the block, show a “small agglomeration, large scattered” distribution pattern, with the trend of urban development in the east–west direction; the number of ECIs in the eastern and western urban areas is relatively small.

From the visualization results (Figure 7), the ECIs are mainly clustered in the urban center, with less distribution in the eastern and western urban areas. This is mainly because the urban center was built early, the population is large, the economic development has been rapid, and the infrastructure is imperfect. Due to the geographical factors of the north and south of Jinan, the city has been expanding to the east and west in recent years; the east and west belong to the newly built areas, with a small resident population, low population density, and insufficiently equipped infrastructure.

3.2. Analysis of Accessibility of Elderly-Care Institutions

The impact of the scale of ECIs on accessibility needs to be taken into account when conducting the accessibility analysis [72,73]. According to the Chinese national norms (GB 50180-2018 [74] Urban Residential Planning and Design Standards), the search range value of pedestrian accessibility takes the spatial and temporal behavioral characteristics of the residents as the standard for the stratified division of residential space and the spatial configuration of public facilities and proposes the 5–10–15-min community living Circle structure. In the 15-min living circle residential area with community service centers (subdistrict level), small ECIs will usually be combined with community service centers. Therefore, the driving time threshold for small ECIs can be set to 15 min. As an important part of the urban service system, large ECIs should serve the whole area of Jinan City, and some scholars [7,14,48] have set the acceptable driving time thresholds for the elderly to arrive at different levels of ECIs as 60 min–90 min. Therefore, the threshold of transportation time for large ECIs was set to 60 min. For medium-sized ECIs, the threshold for driving time was set at 30 min.

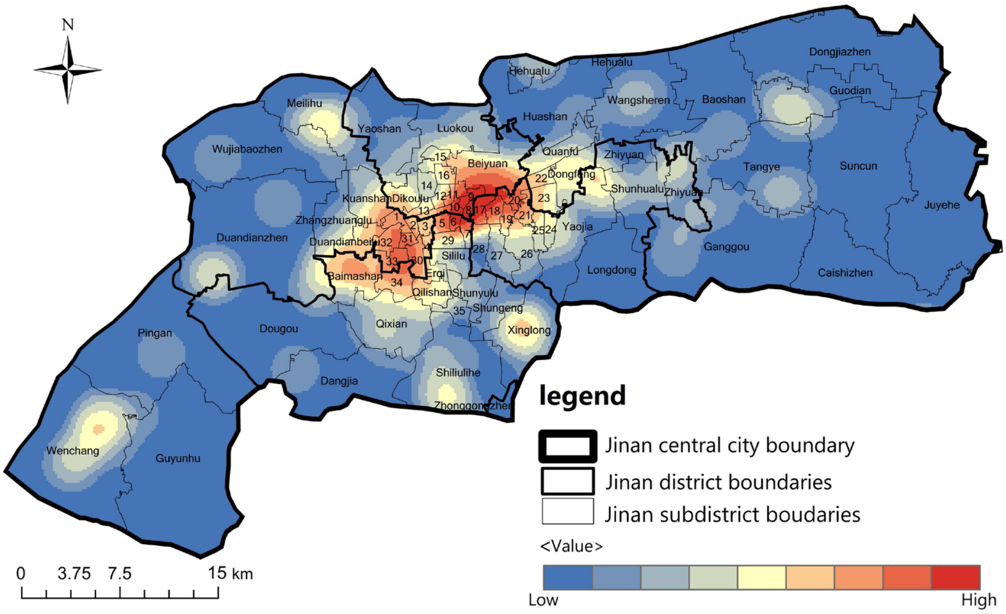


Figure 7. Kernel density map for ECIs.

Visualization of the spatial accessibility of elderly-care institutions in 81 subdistricts in the study area was performed using ArcGIS in the context of effective service thresholds differentiated by size. The overall results indicate the following: (1) The spatial accessibility of small ECIs in Jinan City varies significantly, with a general pattern of high accessibility in the north and low accessibility in the south, high accessibility in the east and west, and low accessibility in the center. The number of accessible beds in each subdistrict in the center shows a more balanced situation, while the number of accessible beds in each subdistrict in the eastern and western suburbs varies greatly. From a subdistrict scale perspective, there are 81 subdistricts in the central city. The average accessibility is 1.39, which is below the overall average of the subdistricts. Out of the total 46 subdistricts, 56.8% have an accessibility below the planning requirement. Among these, six subdistricts have an accessibility of 0, which is lower than the required number of beds per 100 people. This means 73 subdistricts, or 90.1% of the total, do not meet the planning requirements. Only Zhiyuan, Zhonggongzhen, Shunhualu, Hohualu, Guodian, Wenchang, Xinglong, and Kuangshan subdistricts (Figure 8a) meet the planning requirements. (2) The spatial accessibility of Jinan's medium-sized ECIs generally exhibits a pattern of high accessibility in the center-west and low accessibility in the east, with better overall accessibility in Huaiyin District. From a subdistrict scale perspective, the average accessibility value for each subdistrict is 2.87. There are 33 subdistricts that have a lower accessibility value than the average and 50 subdistricts that fall below the planning requirements, which accounts for 61.7% of the total (Figure 8b). The high spatial accessibility values of large ECIs are concentrated in the central part of the city, primarily in the Lixia and Tianqiao districts. From the subdistrict scale, the average value of the accessibility of each subdistrict is 3.18. There are 21 subdistricts below the average value, and 27 subdistricts below the planning requirements, which accounts for 33.3% of the total (Figure 8c). The spatial accessibility distribution of the integrated ECIs does not exhibit any obvious characteristics. Higher accessibility is observed in the four administrative districts located in the center (Huaiyin, Tianqiao, Shizhong, and Lixia District), while lower accessibility is observed in

Lixing District to the east and Changqing District to the west. At the subdistrict scale, the average accessibility value for each subdistrict is 3.37. There are 14 subdistricts below the average value and 20 subdistricts below the planning requirement, which accounts for 24.7% (Figure 8d).

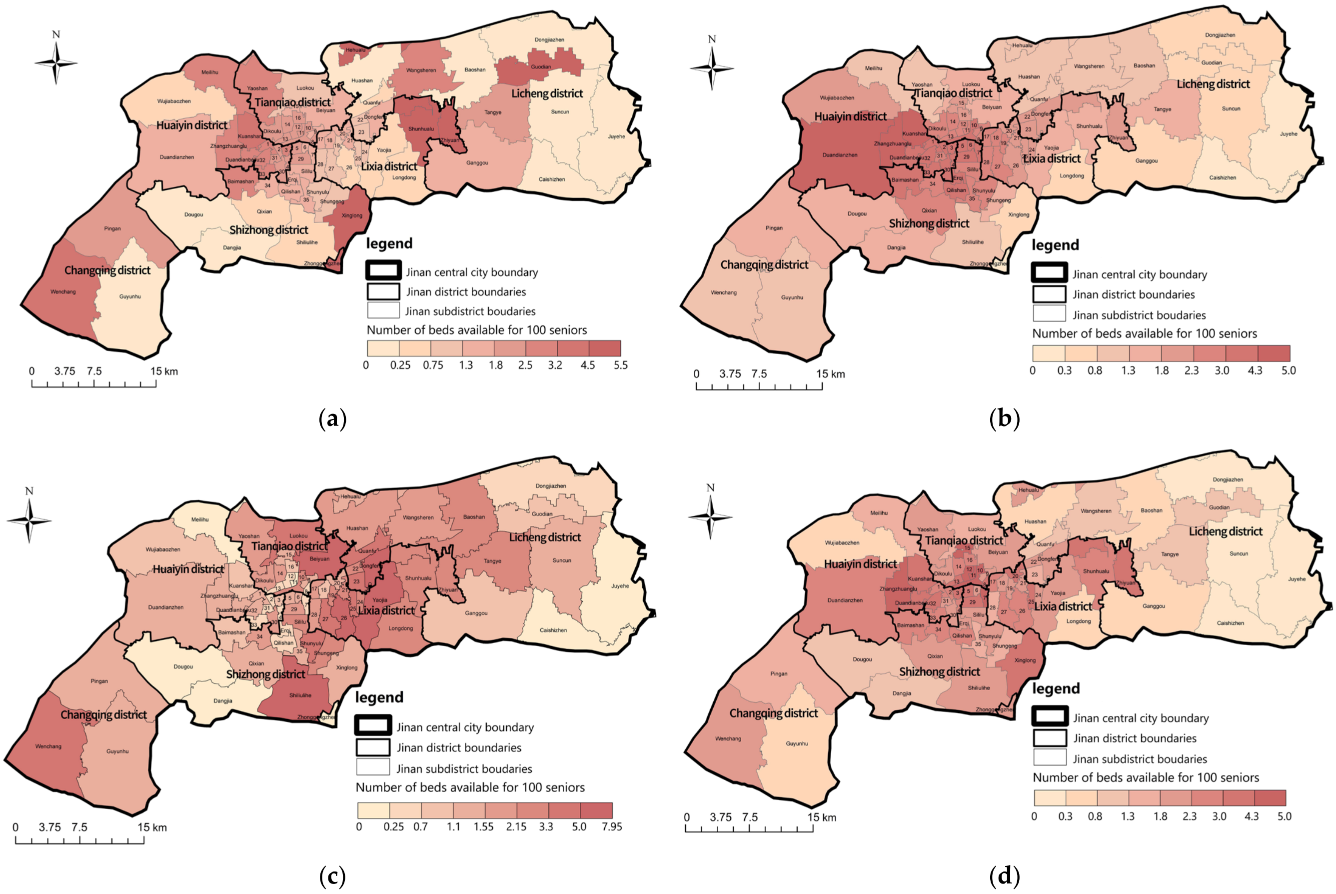


Figure 8. (**a**) Small elderly-care institution accessibility. (**b**) Medium-sized elderly-care institution accessibility. (**c**) Large elderly-care institution accessibility. (**d**) Overall elderly-care institution accessibility.

Overall, the spatial accessibility of ECIs varies significantly from subdistrict to subdistrict. Small ECIs have the weakest supply capacity but cover a large number and wide range of subdistricts. The surrounding area centered on Huaiyin District has a high number of medium-sized ECIs, while the eastern fringe location lacks significant medium-sized ECIs. Small and medium-sized ECIs have limited accessibility in remote areas due to factors such as inadequate infrastructure and isolated roadways. Additionally, the limited number of subdistricts in the city center with poor accessibility can be attributed to high population density and a low supply–demand ratio. Large ECIs and high-quality ECIs are concentrated in the city center. However, the edges of the city have inherently poor roads and a lack of ECIs compared to the central areas. This situation affects the ease of access to care resources for the elderly in the fringe areas. At the planning level, this is also related to the city's structure. The downtown area of Jinan City has a long east–west and short north–south layout, which is influenced by the topography of the region. The presence of mountains in the south and the Yellow River in the north makes it more challenging to establish ECIs in the eastern and western areas compared to the central area [71].

3.3. Evaluation of Spatial Equity in ECIs

3.3.1. Equity in the Spatial Allocation of Resources for ECIs

The Gini coefficients for composite ECIs, large ECIs, medium ECIs, and small ECIs for the study area were calculated from Equations (5) and (6) (Table 4). According to the United Nations Development Programme (UNDP), a Gini coefficient below 0.2 indicates absolute equity and above 0.6 implies a high degree of inequity. A comparison of the United Nations classification criteria reveals that large ECIs in the region exhibit the highest disparity in pension facilities, while small ECIs tend to have a more moderate level of disparity. Additionally, the Gini coefficient of the distribution of all ECIs shows a wide range of disparity. Since the distribution of ECIs is influenced by policies, transportation, and the population using them, it is not exactly equivalent to income distribution, and the degree of its spatial distribution cannot be determined solely by the Gini coefficient.

Table 4. Gini coefficients for different levels of ECI accessibility.

ECI Accessibility	Gini Coefficients
Accessibility of small elderly-care institutions	0.883
Accessibility of medium-sized elderly-care institutions	0.692
Accessibility of large elderly-care institutions	0.603
Accessibility of all elderly-care institutions	0.706

A Lorenz curve is used to quantify the distribution of accessibility of resources for the elderly. It is plotted with the percentage of population on the horizontal axis and the cumulative percentage of accessibility on the vertical axis. Plotting was accomplished by connecting the corresponding points. The Lorenz curve graph is plotted as shown in Figure 9, where the mean line represents the absolute equity reference line, and the higher the degree of bending of the Lorenz curve, the higher the degree of inequity. It can be seen that in order to provide elderly facility resources for the resident elderly population in the middle of a distribution of large differences, more elderly people enjoy fewer ECI resources. Among them, the inequity degree of small ECIs is the highest, which shows that the Gini coefficient of small ECIs is the highest among other items. The distribution of small ECIs will be the key to the equity of distribution of ECIs in the city.

3.3.2. Distribution of Resources for ECIs per Capita

For presenting the relationship between the population in a certain area and the amount of service opportunities provided (supply), an indicator such as the "Land Per Capita" (LPC) can be used [75]. LPC values show the land allocated to specific land use types (services) at each geographic scale on a per capita basis and are calculated as a ratio of available land area to the served population. LPC indicators are used by urban planners to identify shortfalls of available land for each service type based on minimum service standards. This study proposes the use of per capita resources to compare regional differences horizontally. To assess the equity of ECIS allocation among different spatial units, we used the statistical analysis software SPSS 26 to calculate the per capita resource access for each unit (i.e., the locational entropy value) and then used ArcGIS (10.5) to spatially visualize the locational entropy. A location entropy greater than 1 indicates that the per capita enjoyment level of ECI resources within the spatial unit is higher than the overall level of the research scope. If the location entropy is less than 1, it indicates that the per capita enjoyment level of ECI resources within the spatial unit is lower than the overall level of the research scope.

The study shows that (1) the overall ECIs per capita form a low-high-low distribution pattern from the center to the edge, and the ECI resources in the northwest region are higher than those in the southeast region as a whole. About half of the total ECI resources per capita in the region are in a very low range. The total number of space units that are equal to the level of the region is no more than 13.6%, and about 19.8% of the space units enjoy endowment facility resources that are higher than the average level (Figure 10d). (2) Only 7.4% of the streets in which the per capita allocation of ECI resources is small institutions reach the overall per capita level, but their subdistrict coverage is high (Figure 10a). (3) The distribution pattern of per capita ECI resources of medium-sized institutions is similar to that of small ECIs: 20.9% of the subdistrict level per capita resources reach the overall per capita level, and the resource distribution is more balanced than that of small ECIs (Figure 10b,c). (4) The resource allocation of ECIs varies greatly and does not show obvious distribution characteristics. The per capita ECI resources of most subdistricts are at a very low level, and a few high-value districts are far higher than the overall per capita level. On the whole, due to the low land price cost in the peripheral areas and the dense distribution of the elderly population in the city center, the per capita resources of large ECIs in the peripheral areas are higher than those in the city center.

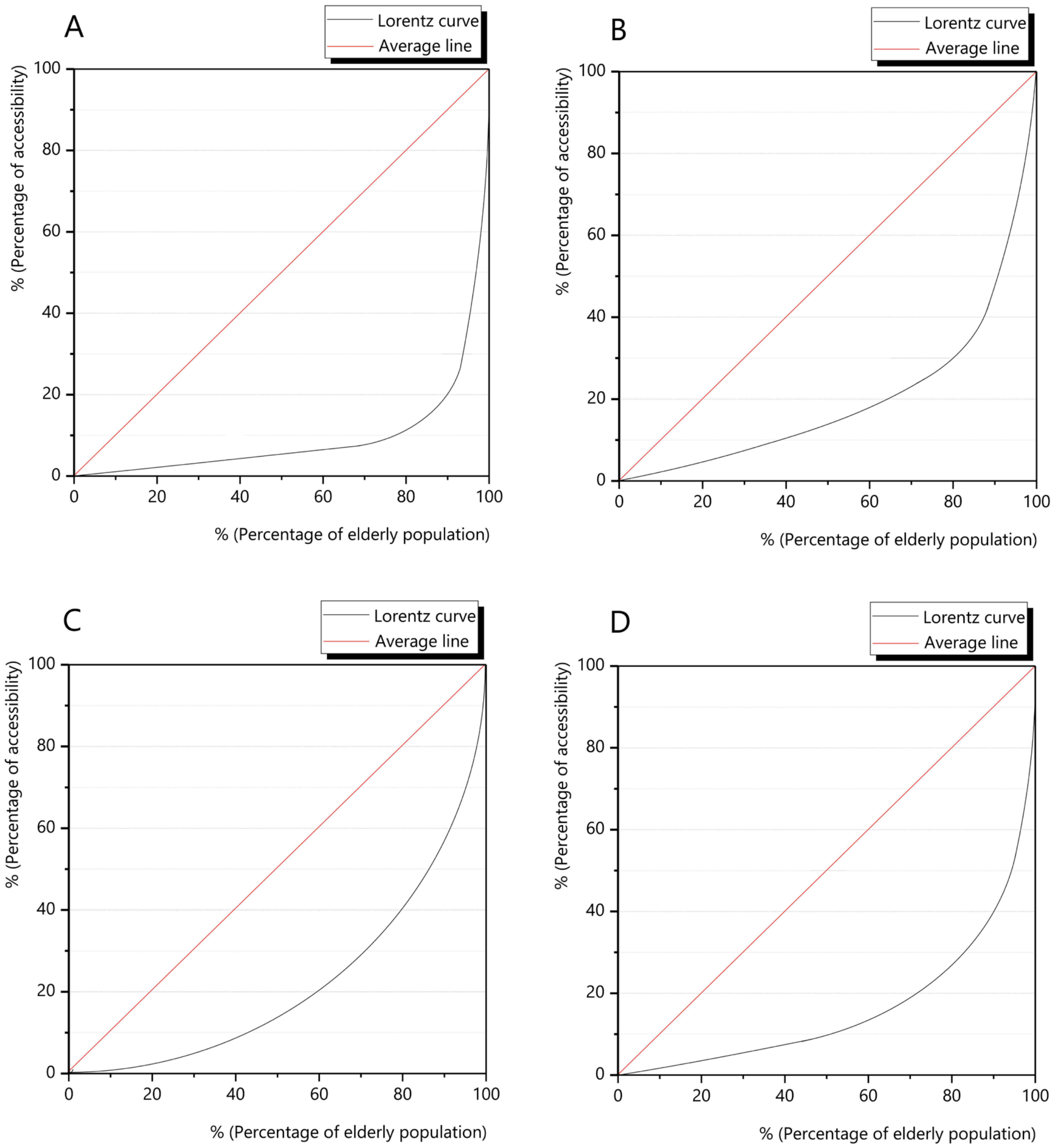


Figure 9. Lorenz Curve: (**A**) small ECIs, (**B**) medium-sized ECIs, (**C**) large ECIs, (**D**) all ECIs.

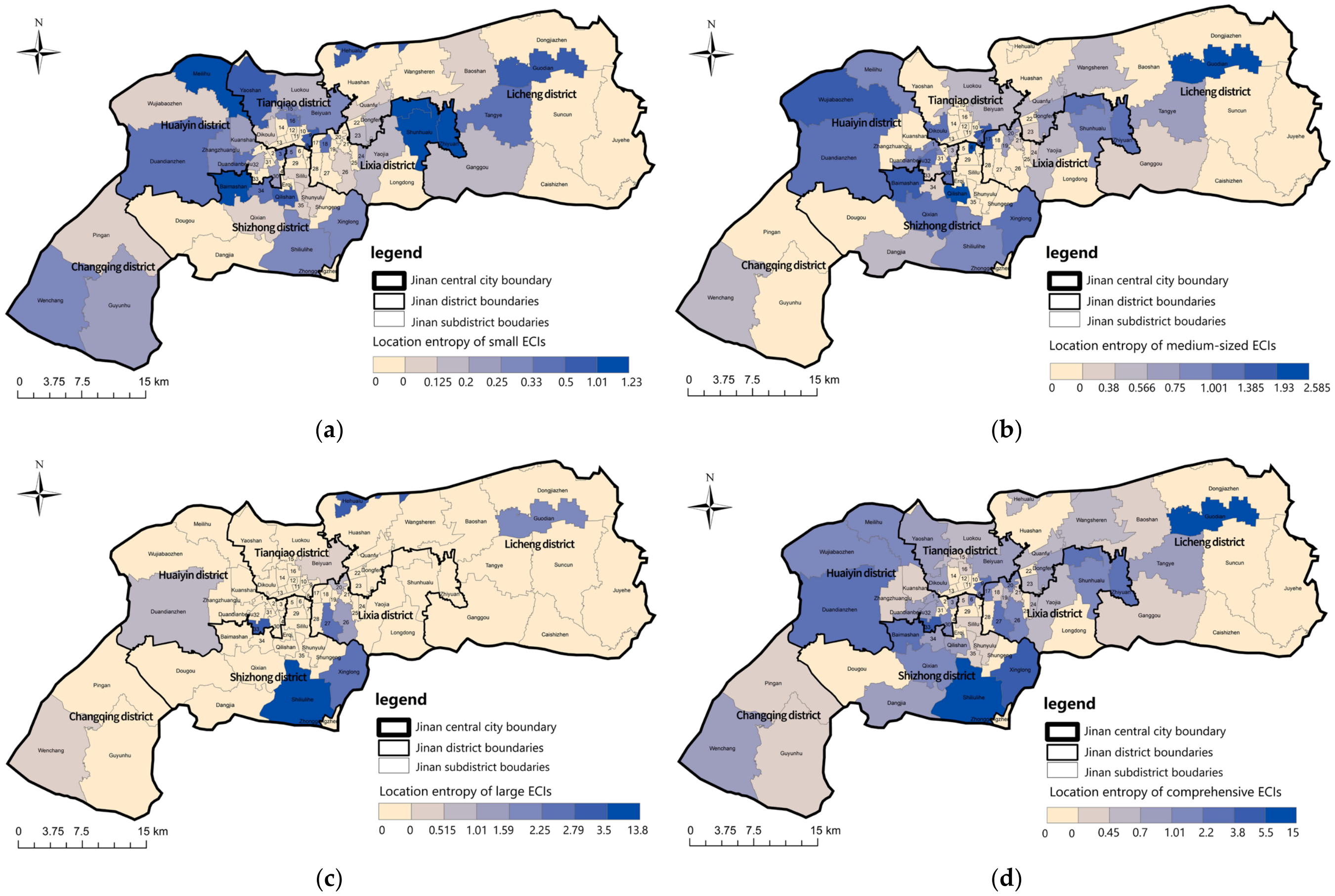


Figure 10. (**a**) Location entropy of small elderly-care institutions. (**b**) Location entropy of medium-sized elderly-care institutions. (**c**) Location entropy of large elderly-care institutions. (**d**) Location entropy of all elderly-care institutions.

From the perspective of distribution, there is a large difference in the per capita ECI resources in the subdistrict, and the distribution of ECI resources is seriously mismatched with the distribution of the elderly population. Although the average ECI resources of some subdistricts are higher than those of other subdistricts, due to the influence of the elderly population density (such as urban centers), the per capita ECI resources are still lower than those of other subdistricts. Affected by the cost of land price and the environment, large ECIs are more often built in the marginal area of vast land and sparse population, while small and medium-sized ECIs are built in the central area of convenient and economically developed transportation due to the impact of travel costs. The central area with high population density and the marginal area with few small and medium-sized ECIs have less resources in terms of ECIs per capita, and the resources of ECIs per capita in the periphery of the central area are higher than those in the downtown and marginal areas. In general, the low value areas are mainly distributed in the central urban area, where the elderly population is relatively concentrated, and the subdistricts with low location entropy are mostly distributed in the central urban area, where the elderly population is dense, the social economy is strong, and the development is relatively advanced. These areas mainly include the core areas at the junction of the Lixia District, Shizhong District, Huaiyin District, and Tianqiao District. In addition, other spatial units with low location entropy can be roughly divided into two categories. The first category is natural scenic areas with sparse population and inadequate facilities, such as Longdong, Huashan and Qianfo Mountain subdistricts. The second category is the urban fringe, which has not yet been developed on a large scale and where the construction of ECIs is lagging behind, such as the eastern part of the Licheng District.

4. Discussion

Through the construction and application of a series of spatial equity evaluation models of ECIs, the study further found that the resource supply of ECIs in the central urban area of Jinan is far from adequate, the accessibility distribution is extremely uneven, the accessibility of the center is high, and the accessibility in the east is significantly low. From the perspective of distribution patterns, the following results were found: (1) Jinan's current central area has a large number of ECIs with excellent geographical locations, convenient transport conditions, and high levels of accessibility, but the concentration of the elderly population in this area results in a lower level of locational entropy. In the face of even greater demands of an aging population in the future, the elderly population in the city central will need to overcome even greater barriers as a result of distance to elderly-care facilities that are further away in the peripheral areas. (2) The peripheral areas of the city center have the second highest number of care facilities after the center, while the elderly population is not as dense as in the city center, the level of care facility services per capita is higher, and the overall level of accessibility of care facilities is average. (3) The distribution of the accessibility of ECIs in the subdistricts on the edge of the city is extremely uneven, showing a low distribution pattern in the east, and the entropy of the district is also in the low-value circle; most of the subdistricts do not meet the requirement of 40 beds per 1000 elderly people in the Opinions.

In view of the above, the following recommendations are made for the graded elderly care system:

(1) For small ECIs, the Gini coefficient and the Lorenz curve confirm their uneven distribution. At the same time, considering the combined accessibility alone can lead to an overestimation of the accessibility of small ECIs and hide their weaknesses in terms of lack of accessibility. When calculating the combined accessibility of facilities, the gap areas are often compensated by large and medium-sized facilities. For small ECIs to meet the 15 min accessibility requirement, a large amount of construction is still needed to fill in the blank areas. Improvement strategies should focus primarily on planning new facilities versus increasing the capacity of primary care facilities. For example, the results of the analysis of the accessibility of the western Changqing District and the eastern Licheng District, which have large zoning areas and lower population densities than other regions, should determine the site layout for new facilities. The land tension population density is high in the center of the Lixia District, and thus the city District should be used mainly to improve the supply capacity of existing facilities. New beds in ECIs should be added on an opportunistic basis, and basic elderly care needs in the region should be met through the conversion and rental of existing buildings.

(2) For medium-sized ECIs, the supply of elderly care resources is relatively adequate, but it is difficult to maximize spatial accessibility and equity, mainly due to the over-concentration of geographic distribution and the large intra-regional accessibility gap. In terms of improvement strategies, it is recommended that, on the one hand, the standard be raised, the scale of existing elderly-care institutions be expanded, and the number of beds be increased, so as to improve the supply capacity of elderly-care institutions; on the other hand, streets with low accessibility and low per capita access to elderly care resources should be selected and new medium-sized institutions should be added in suitable locations, so as to take up the transfer of the service demand from the center of the urban area under the prerequisite of adequately satisfying the local demand for elderly care.

(3) For large ECIs, the difference in locational entropy is greater the higher the rank of the facility, mainly because of the large size difference of large ECIs. Large ECIs, as the highest-ranked facilities, have more service components to offer and more acceptable travel times for residents. Building large ECIs in peripheral areas can improve spatial accessibility. Peripheral areas have lower population densities and smaller residential

areas, and the establishment of high-grade ECIs allows for the planning of more land for transport, reduces the gap between the number of resources and accessibility of ECIs per capita for each street, increases the number of people covered by the facilities, and meets as much as possible the basic elderly care needs of residents of each region.

This paper also has the following shortcomings: (1) Due to the limitations of the Ga2SFCA method, people who can obtain services outside the boundary do not receive service, by default, in the model under actual conditions, so the calculation results of the boundary are different from the actual situation. (2) Because the smallest spatial unit of the available demographic data by age is the subdistrict, as limited by the data, the analysis of the elderly population data in the subdistrict leads to the inaccurate use of the center of mass of the larger subdistrict as the demand point, which affects the final calculation result to a certain extent. (3) Although the use of time cost has become the most accurate way to measure accessibility, there is still a certain gap with the actual situation. Because the average speed of urban traffic is usually used as the traffic speed of the road network, the accessibility will fluctuate greatly for cities, with obvious distinctions during peak hours of traffic. Subsequent studies could incorporate real-time traffic data to geo-code the origin and destination of each trip and measure travel distances on the street network [56] to improve the public facility allocation evaluation systems.

5. Conclusions

For aging cities, recognizing the fair distribution of ECIs is an important step to optimize resource allocation and achieve sustainable development. In recent years, the spatial accessibility of public service facilities has been of great concern [76]. However, there are few studies on the evaluation of the spatial accessibility of multilevel service facilities. In this study, the Ga2SFCA method is used to establish an equity evaluation model to analyze the spatial accessibility and spatial distribution of multilevel ECIs. Under the condition of determining the service thresholds of multilevel ECIs, this paper improves the model, analyzes the spatial distribution characteristics and accessibility of multilevel ECIs, and uses the Lorenz curve, Gini coefficient, and location entropy to evaluate equity. Through multi-stage analysis, we determined areas of inequity. A case study was conducted in downtown Jinan to test the applicability of the method. Optimization measures for the layout of multilevel ECIs in Jinan are further explored in order to provide a learnable method for other cities.

One of the most important aspects of this study compared to other studies [41] is the selection of data. There are accessibility studies that use population fishing nets as demand point data; this study uses more accurate statistical data, using the central point of the street as the population demand point. In addition, the capacity of supply point facilities of ECIs was used as a measure of service capacity to compare and analyze the accessibility of multi-tiered ECIs. When calculating accessibility, some studies have considered the ability of older people to travel (based on average walking speeds) to calculate walking accessibility levels [42]. It has been suggested that the deterioration of older people's physical functioning leads to dependence or reliance on others for their daily activities [77–79]. Therefore, older people are more likely to travel by private car or switch to public transport and walk to their destinations. There have also been studies on the unique transport needs of different age groups, and there have been studies comparing the accessibility of multiple modes of transport [16,56,80]. In this study, the taxi journey path is selected, and the corresponding time costs are set according to the different classes of ECIs. The equity of ECIs is evaluated and compared.

Our main findings are as follows: (1) the spatial distribution of ECIs in the central urban area of Jinan is uneven, the city center is clustered, and the supply and demand do not match. (2) Nearly 25% of the subdistricts do not have enough beds for 100 people. Nearly 50% of the elderly can only obtain 27% of the resources provided by ECIs. (3) Among the three levels of ECI, the large ECIs have the highest spatial equity. Small ECIs have the highest level of inequality in per capita resources in the subdistrict. The service area of small

ECIs is limited, but the number is large. The service capacity of large ECIs is larger, but the number is insufficient. Therefore, to establish a fair multilevel elderly-care system, the reasonable distribution of small ECIs will become key. The results of the study show that the distance factor is the most important factor affecting the accessibility of older persons. Locating facilities close to the residence is a major need of the elderly [81,82]. The spatial distribution of public facilities largely determines the level of accessibility [83,84] and provides geographic relevance for the strategic advancement of China's tiered elderly care system. Many other cities in China—like Jinan—are experiencing an uneven development of multilevel elderly services.

Urban planning is a complex, multidisciplinary, and collaborative process. Planners should carefully consider the need for large amounts of data, various methods, accepted assumptions, and constraints. The model established in this paper can be used as a method to evaluate the equity of ECI distribution and puts forward targeted optimization strategies for inequality situations. Despite some limitations, this study provides a realistic assessment of the spatial accessibility and equity of elderly people's access to services, and the findings can provide a reference for the location and layout of ECIs in the central city of Jinan. The research methodology is valuable for studying the spatial equity of public service facilities in other cities.

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

Funding: This research received no external funding.

Data Availability Statement: Data derived from the current study will be provided to readers upon request.

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

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