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Spatial Layout Monitoring and Optimization of Elderly Care Facilities

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With numerous aging societies worldwide, the world is facing a rapidly growing and already large elderly population. Elderly care facilities have become an important topic. Hence, it is urgent to examine the layouts of public elderly care service facilities, conduct rational planning, and promote the efficient utilization of facility resources. By constructing a Service Demand Equality-Frame Model and performing visualizations based on Geographic Information Systems (GISs), we assessed the degrees of spatial equilibrium between the service capacities of public elderly care services and the demand for them. The spatial accessibility and equality of hospitals, communities, and elderly care facilities in Guangzhou's four main urban districts (Yuexiu, Liwan, Haizhu, and Tianhe) were subjected to scientific evaluation. The results have validated the effectiveness of the econometric model. According to GIS-based visualization, the spatial accessibility distributions of these public facilities are uneven with large gaps between subdistricts. Accessibility peaked in Yuexiu but gradually declined from the city center and Yuexiu to the surrounding areas. We investigated the best quantitative approaches for measuring the spatial accessibility distributions of public facilities such as hospitals and communities to improve spatial layout monitoring and optimization of elderly care facilities.

1. Introduction

The United Nations predicts that by 2060, the global senior population aged 60 and over will reach 1.7 billion.(1) Figure 1 shows the trends of the proportions of the populations aged 65 years and above in some countries.(2) With the rapid growth in the sizes of the elderly populations, the aging trends will accelerate and the proportions of young populations will present trends of continuous decrease. By then, the age structure of the world's population will have changed

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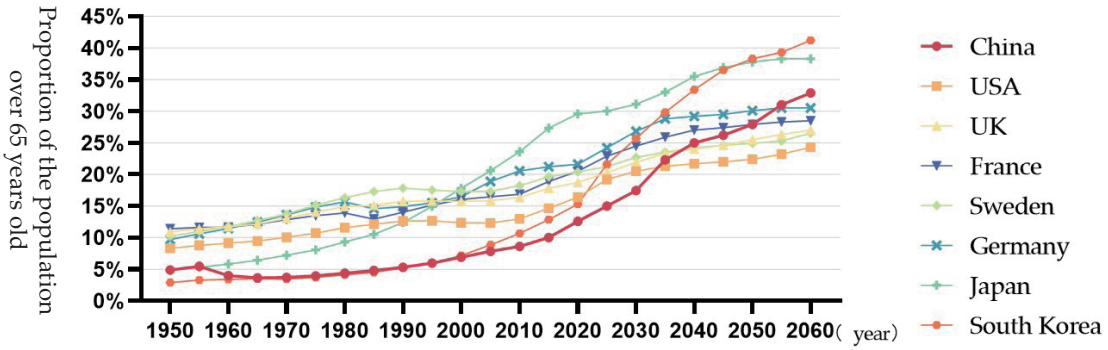


Fig. 1. (Color online) Proportions of elderly populations in some countries from 1950–2060.

substantially because the elderly population aged 65 years and above will have exceeded the younger population aged 15–24 years. This trend is an almost irreversible process. Population aging will impact every nation.

Driven by socioeconomic development, the trend of population aging in China is also accelerating.[3] At the end of the last century, China's elderly population aged 60 years and above accounted for 10% of the total population, which is a sign that China had formally become an aging society. It is also the first country with an elderly population of more than 100 million people.[4] Because of the large base and rapid growth of the elderly population, the proportion increased by about 7% during 2000–2022. The growth rate during this time was more than double the world average, indicating that China would become one of the countries with the most severe population aging and face considerable problems.

Improving the social elderly care service system helps address population aging, accelerate the transformation of the traditional elderly care model, and improve people's well-being. Additionally, effectively addressing the issue of elderly care for the disabled and semi-disabled elderly groups and meeting the rising demand for elderly care services strengthens social harmony and stability. The number of elderly and the need for elderly care services are both rising as the trend toward aging gradually accelerates, but family care resources are steadily declining, underlining the discrepancy between the supply and demand of elderly care service facilities in China. As a vital component of the basic public service system, elderly care service facilities have gradually become a major livelihood issue that has concerned governments at all levels, all orders of society, and the people. In fact, the issue has been receiving increasingly close attention from all walks of life.

2. Literature Review

2.1 Status of related studies

Until the 1980s, institutional elderly care was virtually unknown in China. In this study, we identified three distinct periods of elderly care development. The first development period was 1994–2001. Economic development was still considered to be the solution to the improvement of the conditions of the aging population. Focus was on the construction of elderly homes. The

second development period was 2006–2010 and showed a deeper social inclination with the aim of constructing a harmonious society. The third period comprises 2011–2020. China's central government officially proclaimed a new elderly care infrastructure: 'elderly home care as the foundation, community elderly care as support, and state institutional care as supplement'.(5)

Compared with China, developed countries became aging societies and studied elderly care facilities earlier. The studies on elderly care facilities in developed countries have had different emphases in different periods, focusing on the supply and demand relationships and the types and spatial layouts of elderly care facilities. These studies all provide references for Chinese scholars. Research on the special characteristics of the elderly groups in developed countries explains why geriatric societies have emerged and developed. In fact, five major theories have been put forward to guide the planning of elderly care facilities: the disengagement theory, the replacement theory, the activity theory, the role theory, and the age layer theory. Regarding the spatiotemporal characteristics of the elderly population, scholars from developed countries have focused on the differences and evolution of the geographical distributions of the elderly population from the perspective of demographic geography. The senior population is largely concentrated and higher in metropolitan centers than in suburban and rural areas.

In accordance with socioeconomic development, the elderly care models of developed countries can be divided into four major stages. (1) Model of home-based elderly care:(6) This is the earliest elderly care model. (2) Model of elderly care facilities:(7) After the Industrial Revolution, the West experienced the rapid development of industry, the clear divisions of labor, and improvements in the level of socioeconomic development, which led to the implementation of this model. (3) Model of community care:(8) After World War II, the West went through a new round of development and the British government vigorously promoted this model after 1950. (4) Elderly care model combining community care and elderly care facilities:(9) After the 1960s, the British government was under tremendous financial pressure to vigorously implement community care, which was accompanied by a series of social problems. To alleviate these problems, the government, under the guidance of welfarism, combined elderly care facilities and community care to form mutually reinforcing relationships.

Changes in elderly care models are often accompanied by developments in the types of facility. In developed countries, development in the types of elderly care facility can also be divided into four stages: (1) traditional life care facility, (2) nursing homes, (3) community care facility, and (4) combination of existing home-based elderly care and community care facility with elderly activity centers, elderly apartments, and other facility provided by the government. Developed countries such as the United States, Japan, and Singapore have begun to explore elderly care facilities and facilities with integrated, long-term care functions. Scholars have focused on the location selection, layout characteristics, and accessibility of public service facilities, as well as the social differentiation affecting their spatial layouts.

Studying the location selection and layout characteristics of public service facilities is conducive to realizing the fairness of public service facilities, as well as achieving the goals of rational allocation and layout optimization.(10) Therefore, the principle of fairness should be followed in making rational spatial layouts of public service facilities. Harvey held that urban residents should have fair access to public services, so the spatial layouts of public service

facilities should obey the principles of fairness and rationality.[11] Guagliardo introduced the concept of spatial accessibility, then explored the development of geospatial information systems and spatial accessibility analysis.[12] For the evaluation of the spatial layouts of public service facilities, accessibility research is an important evaluation method used by scholars to analyze the spatial accessibility of public service facilities, such as sports and healthcare facilities. Elderly care facilities constitutes one type of public service facilities. Therefore, the accessibility of public service facilities can be analyzed using geospatial data, Geographical Information System (GIS), and spatial analysis tools. In policy-making, auxiliary analysis can be performed on the unbalanced distribution of facilities at the spatial level[13] to solve the problem of unbalanced distribution.

2.2 Status of related studies in China

Compared with their peers in developed countries, Chinese scholars started late in studying elderly care facility. Notably, there was a major contradiction, especially regarding the supply and demand of elderly care facilities, between the development of elderly care facilities and the growth rate of the elderly population at this stage in China.[14] For this reason, Chinese scholars' studies on elderly care facilities started with system classification and configuration, as well as construction standards, before examining planning strategies, spatial layouts, and so forth.

Cheng and Cui, utilizing the Jing'an of Shanghai as a case study, integrated the improved immune algorithm and GIS to examine the rationality of the layouts of current elderly care facilities, then gave specific recommendations for optimization.[15] Song *et al.* took Shanghai as their research area and studied the spatial configurations of elderly care facilities in terms of preferences.[16] Studies on the configurations and construction standards of elderly care facilities mainly start from policies at the levels of sociology and management science while focusing on the construction and management mechanisms of elderly care facilities.

In the field of planning and construction, the focus is placed on the configuration scales and requirements of elderly care facilities. Yanyan *et al.* examined fairness in the urban districts of Hefe by looking at the needs of the elderly, and then the rationality of the spatial configurations and accessibility of medical facilities.[17] Gu *et al.* studied community-based elderly care facilities in Nanjing, China, in terms of demand orientation and planning coordination, then guided their planning and construction in accordance with a grading and classification system, as well as configuration standards.[18] The majority of researchers have examined the supply and demand of elderly care service facilities, as well as the suitable geographical distribution of these facilities using GIS-based spatial analysis and other techniques.

Because of the continuous intensification of population aging, the planning and construction of elderly care facilities are being studied by increasing numbers of scholars. In particular, the planning strategies of elderly care facilities are a research hotspot among Chinese scholars. Di *et al.* studied the planning strategies of elderly care facilities in Shaanxi Province from the perspective of supply and demand at the provincial macrolevel.[19] Zhang *et al.* analyzed the causality between variables using system dynamics and introduced the state space method for mathematical modeling and simulation analysis, then investigated the supply and demand balance status of elderly care service resources in China.[20] An inductive analysis of the

literature has shown, that provincial and municipal areas are taken as the key research scopes and elderly care facilities are studied for their individual dimensions, such as supply and demand relationships, as well as spatial analysis.

With the continuous emergence of new technologies and methods, some scholars have begun to apply GIS technology to the spatial layouts of elderly care facility. Liu *et al.* performed a scientific evaluation of the spatial accessibility of community-based elderly care facility in Beilin, Xi'an, by using the two-step floating catchment area (2SFCA) method and a GIS-based potential model, then conducted a layout optimization.[21] Yu *et al.* examined community-based elderly care facilities in rural Guangdong Province by using GIS and the nearest distance method to analyze the spatial differences and agglomeration characteristics of spatial accessibility for the optimization of facilities.[22] To examine community life circles, Wan *et al.* comprehensively compared the spatial distribution of elderly residents and the accessibility of elderly day-care centers in typical urban built-up areas in China by using accessibility theory and the spatial analysis method.[23] For the inductive analysis of quality, GIS-based spatial analysis and accessibility analysis provide relatively mature methods for applied analysis.

Population aging, pension facility standards, construction, and research on the spatial distribution of public service facilities are producing favorable results. The spatial distribution of the elderly population has been thoroughly analyzed, and assessment procedures for the spatial organization and design of public service facilities are mature. Beyond configuration and construction requirements, researchers in this field have moved on to spatial planning and optimization. In this study, we restructure the data from a number of past researchers' quantitative evaluation model experiments. A more exhaustive model of metrology is offered. The spatial aggregation capabilities of GISs, when utilized, can provide decision-makers with a more natural manner of giving references for the future architecture of elderly care service facilities.

3. Research Methods

3.1 Definition of service demand equality-frame model (SDE-FM)

The definition of a universal SDE-FM is based on the spatial supply and demand–spatial cost relationships of public services. The definition includes basic concepts such as elderly care services and service demand, as well as the description of the supply and demand of elderly care services based on the spatial relationships of road networks.[24] In the next step, the data model structure built in combination with the SDE-FM can provide a data model basis for the evaluation and planning of the layouts of urban public elderly care facilities.

3.1.1 SDE-FM of concepts

3.1.1.1 Elderly care services

(1) Types of public elderly care service facility

There are three types of public elderly care service facility. 1. Medical service facility (S_1):

Medical service facilities include general hospitals at all levels and specialized geriatric hospitals. Hospitals of different scale grades have different medical service functions. Medical facilities of a low scale grade have only a few community-oriented basic medical functions, such as pharmacies, basic outpatient services, inpatient infusions, and minor surgeries. In contrast, medical facilities of a high scale grade not only possess low-grade functions but also provide advanced medical service functions, such as major sophisticated surgeries. In this study, we are concerned with the service demand of home-based elderly care and only consider the simple routine medical service functions, such as regular geriatric return visits, physical examinations, and influenza treatments. 2. Community facility (S_2): Community facilities include community-based elderly care service centers, service stations, elderly activity centers, retirees' activity rooms, and other facilities affiliated with subdistrict offices, neighborhood committees, and other grassroots management facilities. 3. Elderly care facility (S_3): Elderly care facilities include elderly apartments, retirement homes, gerocomiums, elderly nursing facilities, elderly nursing homes, and social welfare facilities. This facility is equipped with sound medical and life service equipment.

(2) Definition of land for public elderly care services

The Guiding Opinions on Land Use for Elderly Care Facility, issued by the Ministry of Land and Resources in 2014, for the first time clearly defined the scope of land for elderly care service facilities and explicitly stipulated that only land occupied by houses and site facilities that are specifically used to provide life care, rehabilitation nursing, trusteeship, and other services for the elderly can be labeled as land for elderly care service facilities. The land use is limited to medical and health purposes (second class), which belong to the standard land classification item of land for administration and public services (first class) in construction land, with a land-use life of no more than 50 years. Land occupied by commercial facilities such as hotels, hostels, clubhouses, and shopping malls for the elderly does not fall within this scope. Other types of land may be used only for the construction of supporting elderly care service facilities and

Table 1
Types of land for public elderly care services.

COPE	TOPE	SOPE
Medical service facility (S_1)	Medical and healthcare services	General hospitals at all levels Clinics First-aid stations Specialized geriatric hospitals, sanatoria
Community facility (S_2)	Government agencies	Elderly care service centers, service stations
Elderly care facility (S_3)	Real estate	Elderly apartments
	Life services	Civil elderly care service stations
	Cultural entertainment services	Homes for the elderly, elderly activity rooms, chess rooms for the elderly, elderly associations, elderly universities
	Government welfare facility	Retirement homes, elderly care service centers, rest homes, nursing homes for the aged, gerocomiums, elderly nursing facility, social welfare facility

*COPE (Categories of public elderly care service facility); TOPE (Types of public elderly care facility); SOPE (Subtypes of public elderly care facility)

rooms, as well as for the apportionment of corresponding land areas (Table 1).

According to China's Code for Metropolitan Public Facility Planning, Guangzhou, as a Class-III big city, has a land-use planning standard for aged facilities of 0.1–0.3 m^2/person. Guangzhou's "Fourteenth Five-Year Plan" for the development of the senior care service system specifies a land-use building standard of 0.25 m^2/person for elderly care service facilities.

3.1.1.2 Service demand

(1) Demand groups of public elderly care services

China's Standards of Social Welfare Facility for the Elderly defines the elderly as the people aged 60 years and above, which would be regarded as the demand group for elderly care services. With regard to the "smart elderly care" application project in "smart city construction", the traditional daily habits of home-based elderly care, and the insufficient number of professional elderly care facilities in China, the responsible government departments have proposed a "three-in-one" elderly care model, which sets the ratio of home-based elderly care to community-based elderly care to institution-based elderly care as 90:6:4. For analyses and evaluations of the population shouldering the pressures of public elderly care facilities, the ratio of the demand groups can be set to this value.

(2) Demand types of public elderly care services

According to the definition of the demand groups of elderly care services, public elderly care services should be distinguished from social assistance. The service objectives of public elderly care services should not be simply equated to the elderly, the sick, and the impoverished but should also cover the healthy and younger elderly to fully consider the care service demands of the elderly.

The three types of the elderly population (self-care elderly, device-aided elderly, and nursing-cared elderly) in China's Standards of Social Welfare Facility for the Elderly can correspond to the demand groups of the three types of elderly care services (home-based elderly care, community-based elderly care, and institution-based elderly care). Different types of the elderly population have different elderly care service demands.[25]

1. Home-based elderly care is a traditional elderly care model that has been followed for thousands of years in China. Most of the elderly still rely on this model. The cost of elderly care is mainly borne by family members. However, in general, it is difficult for the elderly to receive professional and meticulous care, so their medical care demands are not usually met in time. Physiological aging and frequent diseases make health maintenance the primary concern for the elderly.[26] To visit big hospitals, the elderly must take buses, then enter queues and pay fees to receive physical examinations. Community hospitals and clinics try to make visits more convenient.[27] It should be pointed out, however, that the medical needs of the elderly with major diseases that require long-term hospitalization and long-distance travel are not considered in this paper.
2. Community-based elderly care relies on community facilities to provide daytime life care services, such as housekeeping services and cultural entertainment services. Urban community-based elderly care has the advantages of convenience and timeliness. Taking care

of the daily needs of the elderly eases the burden on family members, strengthens the emotional connections amongst the elderly, and reduces the government's workload by relieving it of the need to micromanage.

3. The elderly who voluntarily choose institution-based elderly care are generally those who have no or only weak self-care ability and who have comprehensive elderly care service demands for life care, health management, spiritual consolation, and emergency rescue. In these regards, elderly care facilities can provide full-time care.

3.1.2 SDE-FM of data

3.1.2.1 Relationships between entity elements

Elderly care services are delivered in space through road networks. In this study, the spatial relationships between entity elements are based on path distance. Service scopes are divided in accordance with the cost impedances of the paths, and public elderly care facilities are measured by two indicators: service areas and action domains. Here, a conceptual distinction is needed (as shown in Fig. 2). Service areas take no account of the spatial competitive relationships between facilities and can be superimposed on each other. In contrast, action domains consider the spatial competitive relationship between facilities and cannot be superimposed on each other. On the basis of 1: n spatial relationships between facility points and demand points, action domains are selected to measure the service scopes of the facility points.

On the basis of theories of human–environment interaction, spatial dynamics, and so forth, the following relationships have been identified between entity elements such as elderly care facilities (hereinafter referred to as *S*), road networks (hereinafter referred to as *N*), and residential areas (hereinafter referred to as *D*): The service capacities of the elderly care facility (*S*) attenuate with path distance in road networks while the action domains of the facility are divided by competition and selection. The service capacities are delivered to the demand groups of elderly care services along the routes of "elderly care facility (*S*)–road networks (*N*)–residential areas (*D*)", i.e., the accessibility of public elderly care services for the demand populations. In the action domains, the demand populations are delivered along the routes of "residential areas (*D*)–road networks (*N*)–elderly care facility (*S*)". The floor areas of various elderly care facilities (*S*) are summarized and counted as the corresponding areas of land use.

(a) (b)

Fig. 2. (Color online) Schematics of distinction between (a) service areas and (b) action domains.

3.2 Evaluation methods of equality of services

The objective of layout evaluation is to measure the level of the equality of public elderly care services, as well as to divide blind spots and screen overloaded facilities, thereby laying a foundation for planning decisions.

3.2.1 Calculation of service demand

The service demand (hereinafter referred to as *SD*) of a residential area (*D*) is the elderly population living in a residential area. It is difficult to obtain the precise elderly population in each residential area but easy to collect the elderly population and residential area number of each district, so the service demand of each demand point can be calculated using the following equation:

$$SD_j = \text{elderly population of each district / residential area number.} \quad (1)$$

SD_j denotes the theoretical elderly population of residential area D_j.

3.2.2 Calculation of service capacity

The service capacities of elderly care facilities (*S*) comprise the population carrying capacity (Population Service, hereinafter referred to as *PS*) and service function sub-base value (Function, hereinafter referred to as *F*). The calculation method is as follows.

(1) Theoretical population carrying capacity PS_i

The specific values of λ and α are available from relevant statistical yearbooks and websites. The theoretical population carrying capacities of the facility (PS_i) can be calculated using Eq. (2) in Table 2. The three types of elderly care facility are graded as follows. 1. Following the Standards for Hierarchical Management of Hospitals and the City Health and Family Planning Yearbook, medical service facilities (S_1) can be graded at four levels on the basis of the average number of beds. 2. Community facilities (S_2), as government agencies or grassroots organizations at the town (township) level and below, can be considered the same and graded at one level. 3. Currently, there is a lack of information on the levels of local elderly care facilities (S_3) on their websites, so they are considered the same and graded at one level.

3.2.3 Calculation of service accessibility (*SA*)

Most studies often adopt travel time and distance as important indicators reflecting the accessibility of services for individuals, thereby forming a distance attenuation model for the accessibility of business service factors, as expressed using Eqs. (3) and (4) below:

$$F = M \times (1 - r), \quad (3)$$

Table 2
Theoretical population carrying capacities of elderly care facilites.

PCOF	ANOB / 1000	SCOF	ANOB	SG	PS_i [Eq. (2)]
Medical service facility (S_1)	λ_1	Class-III hospitals	a_1	1	$\left(\frac{a_2}{\lambda_1}, \frac{a_1}{\lambda_1}\right]$
		Class-II hospitals	a_2	2	$\left(\frac{a_3}{\lambda_1}, \frac{a_2}{\lambda_1}\right]$
		Class-I hospitals	a_3	3	$\left(\frac{a_4}{\lambda_1}, \frac{a_3}{\lambda_1}\right]$
		Clinics	a_4	4	$\left(0, \frac{a_4}{\lambda_1}\right]$
Community facility (S_2)	λ_2	—	a_5	1	$\left(0, \frac{a_5}{\lambda_1}\right]$
Elderly care facility (S_3)	λ_3	—	a_6	1	$\left(0, \frac{a_6}{\lambda_1}\right]$

*PCOF (Primary classification of facility); ANOB/1000 (Average number of beds/1000 people)
SCOF (Secondary classification of facility); ANOB (Average number of beds); SG (Scale grade)

$$F = M^{(1-r)}, \tag{4}$$

where F denotes the effect value of a factor on land at a certain relative distance, M denotes the function sub-base value of a factor, and r denotes the relative time distance of a plot ($r = d/D$, where d is the time distance from a facility point to an area or grading unit; D is the radiation radius of a facility point).

Public elderly care service facilities belong to the business service industry, so this model can be used as a reference to measure *SA*. Travel time is easily affected by road grades and the differences in traffic congestion between different periods, so in this study, we selected the exponential decay model for the service capacities of facilities in accordance with the shortest road network distance in order to reflect the accessibility of community residents to elderly care services. The accessibility measurement models for medical service facilities (S_1) and community facilities (S_2) are expressed using Eqs. (5) and (6):

$$SA_{ij} = F_i^{1-\delta\left(d_{ij}\right)}, \tag{5}$$

$$\delta\left(d_{ij}\right) = \begin{cases} \frac{d_{ij}}{R_i}, & d_{ij} \le R_i \\ 1, & d_{ij} > R_i \end{cases}, \tag{6}$$

where SA_{ij} denotes the *SA* score of service facility S_i relative to demand point D_j, $\sigma(d_{ij})$ denotes the spatial constraint, d_{ij} denotes the shortest path distance from demand point D_j to the nearest

facility S_i, R_i denotes the threshold of the radius of action of facility S_i, and F_i denotes the service capacity index of service facility S_i. This method can be implemented using the Origin-Destination tool of the GIS software, ArcGIS.[28]

3.3 Planning decision method for facility optimization

The subject of this study is public elderly care services. Therefore, only the service demand of the elderly is considered in planning decisions, and the full coverage of elderly care services is taken as the objective of the planning. The first step is to solve the problem of the unbalanced spatial distribution of service supply and eliminate blind spots by adding new facilities. The next step targets the contradiction between the supply and demand of services in terms of quantity and takes optimization measures for elderly care facilities (S) to balance the capacities of the facility. Finally, the results of the planning scheme are optimized and evaluated. The planning decisions for an elderly care facility should be made from high-grade to low-grade functions in the proper order. The results of the planning decisions of high-grade functions should be optimized and evaluated at each grade before proceeding to the planning decisions of the next grade of the functions, because high-grade facilities comprise low-grade functions and the spatial distributions of the low-grade functions are affected by the planning decisions of high-grade functions.

4. Results and Discussion

4.1 Overview of the study area

According to the 2020 global city ranking released by Globalization and World Cities (*GaWC*), Guangzhou is one of the six Chinese cities ranked among the top 50 cities in the world[29] and is the third largest city in southern China.[30] The research subject of this study is the city's four main urban districts (Yuexiu, Liwan, Haizhu, and Tianhe) and the 79 subdistricts under their jurisdictions, which comprise an administrative area of 279.52 km^2 and a permanent population of 6.338 million people as of 2020.[31] In Guangzhou's four main urban districts, elderly populations have grown rapidly in recent years. The large senior populations in Guangzhou's four main urban districts make it difficult to build elderly care services. The growing elderly population and aging are boosting demand for elderly care facilities and worsening the supply–demand gap. Figure 3 shows the research region.

4.2 Evaluation and calculation results

4.2.1 Spatial distribution of elderly care service demand

Table 3 was obtained through calculations involving the relevant data from the Guangzhou Statistical Yearbook 2021. The proportion of the population aged 60 years and above in

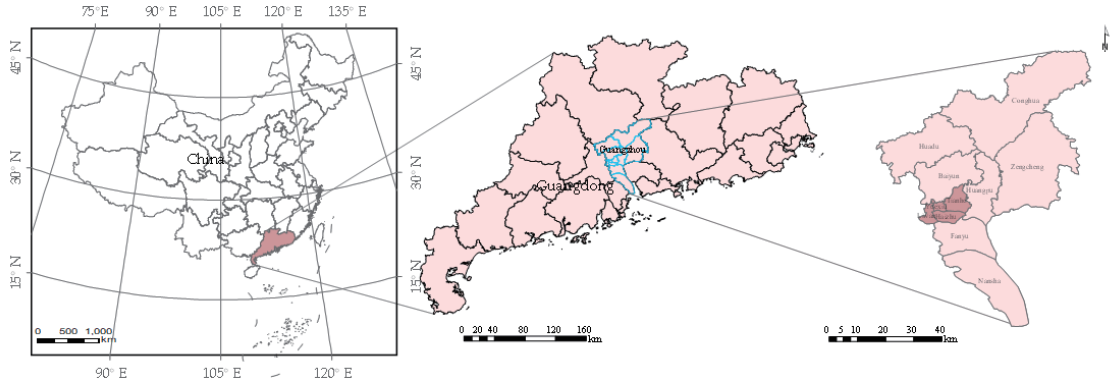


Fig. 3. (Color online) Schematic of scope of study area.

Table 3
Calculation parameters of elderly care service demand.

Parameter name	Parameter value	Unit	Description
Total number of registered households in Guangzhou in 2020	3221.068	1000 households	Data derived from Guangzhou Statistical Yearbook 2021
Total registered population in Guangzhou in 2020	9851.142	1000 people	
Population aged 60 years and above in Guangzhou in 2020 (household registration statistics)	1799468	People	
Average number of people per household = total registered population / total number of registered households	3.0583	People	Calculated from parameters #1–3
Proportion of the elderly population = population aged 60 years and above / total registered population	18.27	%	
Average number of elderly people per household = average number of people per household * proportion of the elderly population	0.5588	People	

Guangzhou reached 18.27% in 2020, thus implying a high degree of aging.

The service demand of each residential area (SD_j) is calculated using Eq. (1). According to the ratio of home-based elderly care/community-based elderly care/institution-based elderly care (90:6:4), the total population with elderly care service demand is 1.79995 million people. Table 4 shows the theoretical demand populations of various public elderly care facilities. Nansha has the smallest population with service demand, whereas Yuexiu has the largest.

Figure 4(a) shows the spatial distributions of residential areas (D) in the main urban districts of Guangzhou. Most of the residential areas are located in areas with dense roads in the city center. According to the spatial distribution of the population with elderly care service demand [Fig. 4(b)] and the map of Guangzhou, elderly care service demand is mainly concentrated in Yuexiu, Haizhu, and Tianhe. There may be excess service demand in areas and subdistricts with agglomerated elderly care service demand, which would require further analysis and confirmation.

Table 4
Statistics of populations with elderly care service demand in Guangzhou.

AD	TDP	Demand population of S_1	Demand population of S_2	Demand population of S_3
Liwan	223.1	200.79	13.386	8.924
Yuexiu	314.3	282.87	18.858	12.572
Haizhu	284.5	256.05	17.07	11.38
Tianhe	142.4	128.16	8.544	5.696
Total	964.3	867.87	57.858	38.572

* (unit: 1000 people); AD (Administrative district); TDP (Total demand population)

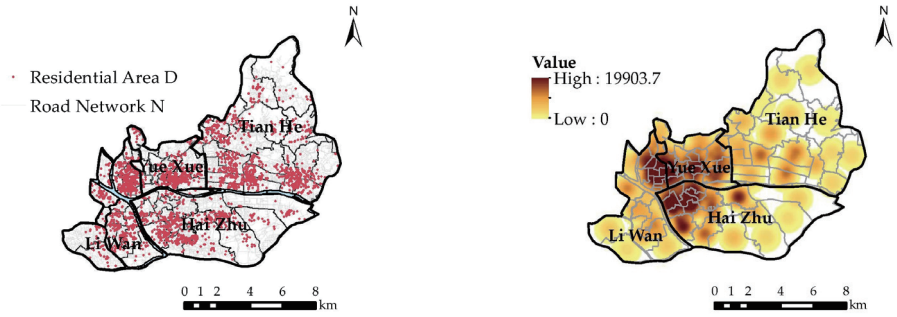


Fig. 4. (Color online) Density distribution of residential areas and demand population in main urban districts of Guangzhou. (a) Spatial distributions of residential areas and (b) kernel density distributions of populations with elderly care service demand.

4.2.2 Spatial distributions of service capacities of facility

4.2.2.1 Medical service facility (S_1)

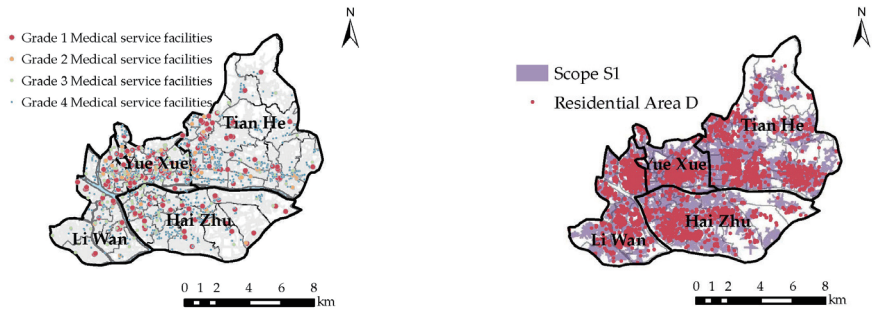
(1) Theoretical population carrying capacities

Prepared according to Eq. (2), since medical services are provided for residents of all ages, the theoretical population carrying capacity should be corrected through multiplication with the proportion of the elderly seeking medical treatment. According to the data released in the latest Urban Statistical Yearbook of Guangzhou, at the end of 2020, community hospitals served 125960800 permanent residents and 23013038 people aged 65 years and above. In 2020, Guangzhou had 1460221 people aged 65 years and above, as well as 2130496 people aged 60 years and above. Hence, the proportion of the elderly aged 60 years and above seeking medical treatment was calculated to be about 26.66%. Table 5 also shows the theoretical population carrying capacity of all medical institutions. The overall theoretical population carrying capacity of Guangzhou's medical care facilities (S_1) is 722.31 thousand persons out of a total population of 867.87 thousand people, resulting in a shortage for 145.56 thousand people.

Table 5
Theoretical population carrying capacities of medical service facilities by grades.

	PCOF	ANOB/1000	SG	Number	ANOBF	POESMT (%)	PS_i	Total PS_i of the main urban districts of Guangzhou
(a) According to average number of beds	S_1	5.42	1	31	382.66	26.66	(0.79, 18.82]	583.49
			2	67	15.99		(0.09, 0.79]	52.71
			3	579	1.76		(0.08, 0.09]	50.26
(b) According to average number of health workers	(S_1)	9.49	4	478	2.67	26.66	(0,0.08]	35.85
	Total	—	—	1155	—		—	722.31

*(unit: 1000 people); PCOF (Primary classification of facility); ANOB/1000 (Average number of beds/1000 people); SG (Scale grade); ANOBF (Average number of beds/facility); ANOHW (Average number of health workers); POESMT (Proportion of the elderly seeking medical treatment)



(a) (b)

Fig. 5. (Color online) Distribution of the range of elderly services in medical service facility. (a) Spatial distributions of medical service facilities (S_1) in main urban districts of Guangzhou by grade and (b) action domains of medical service facilities and spatial distributions of residential areas (D) (R_1 = 1000 m).

(2) Service scopes of facility spaces

Figure 5(a) shows the spatial distributions of medical service facilities (S_1) at all grades. Yuexiu has the largest number of medical service facilities.

The action domains of the facility were established by Network Analyst. Figure 5(b) shows the spatial distributions of the service scopes of the medical service facilities S_1 in Guangzhou. Both Yuexiu and Liwan have high coverage, whereas Haizhu and Tianhe have many uncovered areas. The residential areas uncovered by the action domains of the medical service facilities S_1 are specifically distributed in the Fenghuang Subdistrict, Changxing Subdistrict, Yuangang Subdistrict, Tangxia Subdistrict, and Huangcun Subdistrict of Tianhe, as well as in the Guanzhou Subdistrict and Huazhou Subdistrict (south) of Haizhu.

4.2.2.2 Community facility (S_2)

(1) Theoretical population carrying capacity PS_i and spatial distribution

According to the Layout Planning of Elderly Care Facility of Guangzhou (2019–2025),

Table 6
Calculation results of theoretical population carrying capacity of community facilities for the elderly.

PCOF	ANOB / 1000	SG	Number	ANOBF	PS_i	Total theoretical PS_i of the main urban districts of Guangzhou
Community facility (S_2)	56.24	—	101	83.8	1.49	150.49

*(unit: 1000 people); PCOF (Primary classification of facility); ANOB/1000 (Average number of beds/1000 people); SG (Scale grade); ANOBF (Average number of beds/facility)

community retirement homes in the city will have 101200 beds by 2025, and the average number of beds/1000 people for those aged 60 years will reach 101200 ÷ 1799468 = 56.24 beds/1000 people. Table 6 shows the theoretical population carrying capacity calculation findings.

Figure 6 shows that the core areas of Yuexiu and Jiangnan Middle Subdistrict, Sushe Subdistrict, Changgang Subdistrict, Nanhua West Subdistrict, and Shayuan Subdistrict of Haizhu have relatively high theoretical population carrying capacities.

(2) Service scopes of facility spaces

Figure 7(a) shows the spatial distributions of community facilities. Liwan has the largest number of community facilities (S_2). The spatial distributions of community facilities are characterized by agglomeration, especially in Liwan and Haizhu . Figure 7(b) shows that the action domains of the community facility have a relatively low overall coverage over residential areas and that the coverage is slightly high in Yuexiu. There are many uncovered residential areas in each administrative district, thus implying that the spatial configurations of the service resources of the community facility are unbalanced.

4.2.2.3 Elderly care facility (S_3)

(1) Theoretical population carrying capacity PS_i and spatial distribution

According to the information from the Elderly Care Service Information Network of Guangdong, the number of beds in various elderly care facilities is irregular, and facilities with available data on beds only account for 40.14%, so it is impossible to classify various elderly care facility by scale grade on the basis of the number of beds. In this paper, elderly care facilities (S_3) are classified into one grade. After the information on the grades of elderly care facilities is completed, the layout levels of elderly care facilities at each functional grade can be further studied.

According to the Layout Planning of Elderly Care Facility of Guangzhou (2019–2025), the average number of beds/1000 people aged 60 years and above at social elderly care facilities in Guangzhou will reach 40 by 2025. Table 7 provides the theoretical population carrying capacities of the elderly care facilities.

Figure 8 shows that Yuexiu and Haizhu are the districts where the theoretical population carrying capacities of the medical service facilities (S_3) are relatively high. These do not fit high-demand senior care locations.

(2) Service scopes of facility spaces

Referring to the selection results of the service radii of elderly care facilities in previous

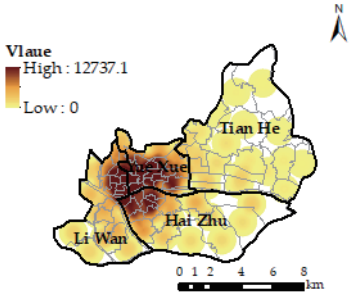
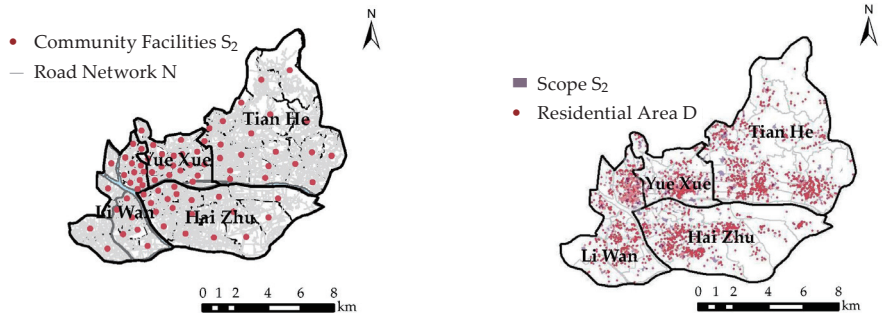


Fig. 6. (Color online) Kernel density distributions of theoretical population carrying capacities of community facilities (S_2) in main urban districts of Guangzhou.



(a) (b)

Fig. 7. (Color online) Distribution of the range of elderly services in community facilities. (a) Spatial distributions of community facilities (S_2) in main urban districts of Guangzhou and (b) action domains of community facilities and spatial distributions of residential areas (R_2=500 m).

Table 7
Statistics of theoretical population carrying capacities of elderly care facilities.

PCOF	ANOB / 1000	SG	Number	ANOBF	PS_i	Total PS_i of Guangzhou
Elderly care facility (S_3)	40	—	58	263	6.58	381.35

* (unit: 1000 people); PCOF (Primary classification of facility); ANOB/1000 (Average number of beds/1000 people); SG (Scale grade); ANOBF (Average number of beds/facility)

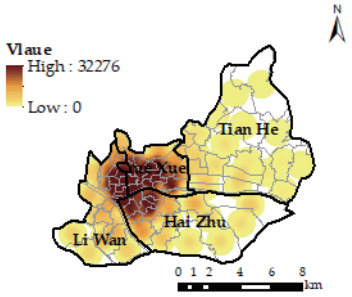
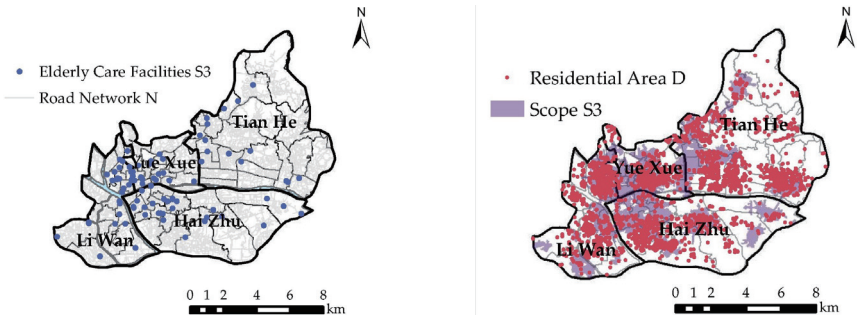


Fig. 8. (Color online) Kernel density distribution of theoretical population carrying capacities of elderly care facilities (S_3) in the main urban districts of Guangzhou.



(a) (b)

Fig. 9. (Color online) Distribution of the range of elderly care services in elderly care facilities. (a) Spatial distribution of elderly care facilities (S_3) in the main urban districts of Guangzhou and (b) action domains of elderly care facilities and spatial distribution of residential areas (R_3 = 1500 m).

studies, we set the service radius of elderly care facilities (S_3) to 1500 m. Figure 9(a) shows the spatial distribution of elderly care facilities, which are most densely agglomerated in Yuexiu and its surrounding areas, but Liwan and Haizhu have the largest numbers of elderly care facilities.

Figure 9(b) shows the spatial distribution of the action domains of the elderly care facilities in Guangzhou. There are many residential areas uncovered by the action domains of the elderly care facilities in each administrative district. Overall, there is sound service coverage in Yuexiu, Haizhu (Jiangnan Middle Subdistrict, Sushe Subdistrict, and Nanhua West Subdistrict), and Liwan (Huadi Street and Chongkou Street).

4.2.3 Spatial distribution of SA

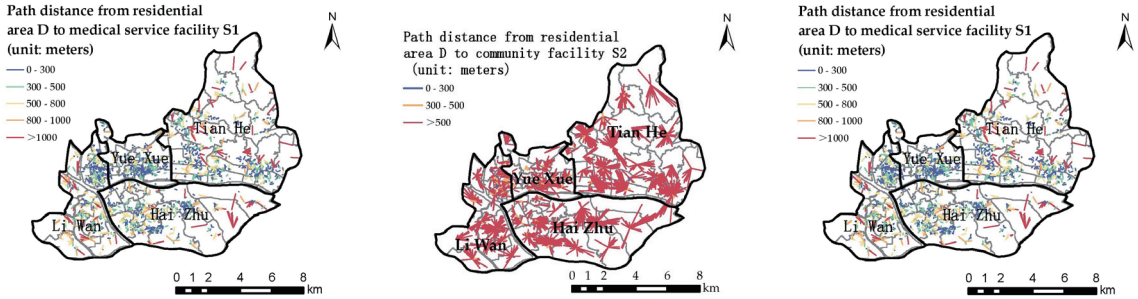
The path distance from demand point D_j to the nearest facility S_i is acquired using the *OD* tool of ArcGIS.

4.2.3.1 Medical service facility (S_1)

As shown in Fig. 10(a) below, the residential areas with the shortest path distances to medical services are concentrated in Yuexiu. The residential areas with relatively short path distances are distributed in the south of Tianhe, the west of Haizhu , and the Huadi and Chongkou Subdistricts of Liwan. There are many residential areas without access to S_1 services in the Fenghuang, Lianhe, and Wushan Subdistricts of Tianhe, the Pazhou, Changzhou, and Guanzhou Subdistricts of Haizhu, and the Hailong and Dongjiao Subdistricts of Liwan .

4.2.3.2 Community facility (S_2)

Figure 10(b) shows the spatial distribution of the path distances from residential areas to community facilities. The residential areas with short path distances to community facility



(a) (b) (c)

Fig. 10. (Color online) Accessibility analysis of elderly care facility by level. (a) Path distances from residential areas to medical service facilities (S_1), (b) path distances from residential areas to community facilities (S_2), and (c) path distances from residential areas to elderly care facilities (S_3).

services are concentrated in Yuexiu and the north of Liwan. There are many residential areas without access to S_2 services in each administrative region.

4.2.3.3 Elderly care facility (S_3)

Figure 10(c) shows the spatial distribution of the path distances from residential areas to elderly care facilities. The residential areas with the shortest path distances to elderly care facility services are concentrated in Yuexiu and the northwest of Haizhu. There are many residential areas without access to S_3 services in the Xintang, Lianhe, Changxing, Xiancun, and Yuancun Subdistricts of Tianhe, the Guanzhou, Nan-zhou, Chigang, Nanshitou, and Ruibao Subdistricts of Haizhu, and the Hailong, Dongjiao, and Bai-hedong Subdistricts of Liwan.

4.2.4 Spatial distribution of blind spots

4.2.4.1 Medical service facility (S_1)

Observations have revealed that the spatial distribution of blind spots of medical services presents the following patterns: (1) road conditions are unfavorable at the boundaries of the main urban districts of Guangzhou, and the path distances to medical services are relatively long, and (2) the type of land use limits the layouts of medical facilities around water systems and green spaces, resulting in an insufficient number of facilities.

4.2.4.2 Community facility (S_2)

The phenomenon of unbalanced supply and demand is widespread in community-based elderly care services in the main urban districts of Guangzhou. The areas with high population densities are distributed in the core areas of Yuexiu and the Jiangnan Middle, Sushe, Changgang, Nanhua West, Longfeng, and Shayuan Subdistricts of Haizhu. The population densities in the east of Tianhe and the south of Liwan are relatively low, which is consistent with the service coverage of the community facilities shown in Fig. 8. Residential areas that are blind spots are

mostly distributed in areas with a low density of community facilities. This pattern implies that the small number of community facilities (S_2) is the main reason why such residential areas have no access to elderly care services.

4.2.4.3 Elderly care facility (S_3)

The blind spots of elderly care facilities (S_3) are mostly distributed in the marginal areas of the study area and around water systems. The reasons why such residential areas have no access to elderly care services include the small number of elderly care facilities (S_3), as well as the unbalanced supply and demand of services.

4.3 Optimization results of facility

Liwan has the largest number of new medical service facilities and the largest number of new Grade-1 medical service facilities, which is consistent with the fact that the district has the largest demand population. Yuexiu has the smallest number of new facilities, for the same reason. (Table 8).

4.4 Unbalanced supply and demand

Of the three types of elderly care facility in the main urban districts of Guangzhou, Yuexiu has the highest comprehensive service coverage, whereas Tianhe and Liwan have the lowest. The causes of the unbalanced supply and demand of elderly care services are analyzed below.

4.4.1 Supply

(1) The spatial distribution of elderly care facilities is irrational. The layouts of the elderly care service facilities have gone through a long historical process and incorporate factors such as location and housing prices. (2) The spatial distribution of elderly care facilities is unbalanced. The area with the highest agglomeration density is located in Yuexiu, an old urban district with the soundest rate of supporting public service facilities. (3) The number of medical service

Table 8
Scale grades and numbers of new facilities (B).

No.	AD	Number of various scale grades of B					Actual total PS_i of B
		Grade 1	Grade 2	Grade 3	Grade 4	TTL	
1	Liwan	5	23	17	0	45	58.4
2	Yuexiu	1	5	2	0	8	7.4
3	Haizhu	0	8	2	4	14	21
4	Tianhe	1	4	9	0	14	24
TTL	—	7	40	30	4	81	110.8

*AD (Administrative district); TTL (Total)

facilities is insufficient and their theoretical carrying population is 722.31 thousand people out of a total of 867.87 thousand, which means that 145.56 thousand people would not have access to medical services.

4.4.2 Demand

In some cases, elderly care service demand is located beside water systems, which are not convenient for traveling. The land-use types are mostly public green spaces, scenic areas, and protected green spaces, which are unsuitable for the development and construction of elderly care service facilities.

4.4.3 Supply and demand

(1) There is poor coordination of supply among the three elderly care models. According to China's "three-in-one" elderly care model, which sets the ratio of home-based elderly care/community-based elderly care/institution-based elderly care to 90:6:4, the current medical service facilities in the main urban districts of Guangzhou are under high carrying pressure, whereas community facilities and elderly care facilities are under low carrying pressure. (2) There is poor coordination between the supply of medical service facilities and the spatial distribution of the demand population. (3) Moreover, there is poor coordination between the supply of community and elderly care facilities for the spatial distribution of the demand population. Both type of facility face the problem of oversupply. However, there are many blind spots in the spatial human–environment interaction.

In summary, the proportion of the elderly population must be adjusted under various elderly care models. It is also necessary to encourage more elderly people to choose community-based elderly care and institution-based elderly care, increase the construction of community facilities and elderly care facilities, add comprehensive elderly care service equipment at facilities, and reduce the carrying pressure on medical service facilities.

5. Conclusions

5.1 Conclusions

By studying the spatial supply and demand–spatial cost relationship of public services, in this study, we formulated the SDE-FM, which can use the spatial relationships of road networks to better analyze the spatial distributions of public elderly care service facilities. The model developed in this study, combined with GIS, can monitor blind spots in the spatial distribution of elderly facilities and effectively assist the government in providing elderly care services. With the gradual aging of the population, the demand for public elderly care services and facilities has been increasing rapidly. This study has the following contributions to the literature. First, it presents the SDE-FM used to measure the spatial accessibility of three types of facility. Second, it can provide information on the adjustments and directions of the future planning of the three types of facility, improve the spatial configurations of public service resources, and optimize the

supply of fair and equitable elderly care services. In this paper, we proposed recommendations for optimization in terms of the boundaries of the central urban districts and the resources for elderly care services, as well as offered references for promoting the equality of elderly care resources in Guangzhou.

A rigorous study of the supply and demand matching of elderly care service facilities in Guangzhou's four major urban districts was undertaken. Below are the empirical findings.

(1) The supply and demand of public elderly care services are unbalanced. Medical service facilities are under high carrying pressure, and there is a gap of 145.56 thousand people between the theoretical population carrying capacity and the demand population. The carrying pressure on facilities is polarized, i.e., some facilities are overloaded, whereas others are operating well below capacity. In contrast, community facilities and elderly care facilities are under low carrying pressure. The remaining capacity of the community facilities is 92.63 thousand and that of the elderly care facilities is 342.78 thousand.
(2) After a feasibility analysis, the final planning decision for the main urban districts of Guangzhou was to construct 81 new facilities. After planning, the quantitative ratio between various scale grades of medical service facilities in the main urban districts of Guangzhou was roughly Grade 1:Grade 2:Grade 3:Grade 4 = 38:107:609:482 ≈ 3.07%:8.66%:49.27%:38.99% = 3:9:49:39. A large number of facilities in Tianhe are distributed in sparsely populated areas where the actual total theoretical population carrying capacity fails to meet the capacity standard. There is a scarcity of high-quality medical service facilities in densely populated areas, putting excessive strain on the existing facilities and resulting in a shortage of elderly care services.

In summary, this study improves the understanding of the service capacity, as well as the level of supply and demand of elderly care facilities, in Guangzhou, promoting the establishment of an elderly care service system based on home care, assisted by community care, and supported by institutional care in order to develop an elderly care model characterized by the combination of medical care, healthcare, and nursing.

5.2 Policy recommendations

(1) On the basis of the service pressure calculations of the three types of facility, it is recommended that community-based and institution-based elderly care models be selected for the main urban districts of Guangzhou. The government can encourage the opening of green channels for appointments at elderly care facilities and medical facilities to reduce the carrying pressure on medical service facilities. In accordance with the theoretical population carrying capacities of the facility, the ratio of home-based elderly care/community-based elderly care/institution-based elderly care should be set to 72.23:15.05:38.14 ≈ 57.60%:11.99%:30.41% ≈ 58:12:30.
(2) Currently, there are a series of problems, including a lack of expertise in most community- and home-based elderly care facilities, inadequate funding and policy support from the government, inadequate quantity of service personnel and quality of services to meet the needs of the elderly, and limitations of the service types to superficial needs. To solve these

problems, it is recommended that the government should continue to support grassroots elderly care service projects and encourage the construction of new elderly care service systems based on communities. Efforts should also be strengthened to develop smart elderly care communities, add elderly care equipment to community facilities, intensify the training of institutional personnel, and create elderly care service jobs. In distant locations with a demand for additional senior care facilities, the government can provide subsidies, such as operational subsidies and tax incentives based on bed count, and encourage private enterprises to engage in PPPs to promote the elderly care industry.

(3) Because of the excessive carrying pressure on medical service facilities in the main urban districts of Guangzhou, it is recommended to increase the number of medical service facilities and improve the standards of bed construction for the elderly. For facilities under capacity, the recommendation is to investigate the operating statuses of public elderly care facilities and rectify those under capacity in order to avoid the waste of public resources and land resources. For residential areas with blind spots in remote areas where the land is unsuitable for the development and construction of elderly care service facilities, infirmaries and elderly care service rooms can be built.

(4) Because of the lack of data on the elderly population at the community level, alternative community family and population grid data were used for estimation. Then, the results were validated by using the elderly population of the given subjects and selected communities/villages obtained from the field survey. The estimated dynamic populations of some communities may affect the results, and improvements can be made in future research by considering more factors. The main urban districts of Guangzhou were selected as the study areas to assess the accessibility and equality of three types of facility. Other region-wide validations can be explored in future research. Therefore, the accessibility and equality of public elderly care service facilities in rural areas, as well as in areas with low road accessibility, are also worthy of in-depth research.

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