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Senior-friendliness evaluation of service facilities in living circles of residential communities

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Abstract: An evaluation of senior-friendliness of service facilities in living circles for residential communities provides insights on challenges in an aging society. This paper clarifies the activity range and features of service facilities for the elderly by reviewing standards, specifications, and research literature; the paper also identifies living circles with 10-min and 5-min walking distance ranges for the elderly based on the area of interests (AOI) and point of interests (POI) data from residential communities. Using population raster data from WorldPop and census data, the paper presents the calculated proportion of the elderly as the basis for estimated demand. Weighted kernel density is used to demonstrate the distribution features of service facilities in living circles for residential communities and to assess the suitability of basic guaranteed facilities and the convenience of quality enhancement facilities. Global Moran's I and Kendall correlation coefficient are used to calculate the relevancy of the spatial distribution of these service facilities. Finally, taking Huangpu District and four sub-districts in central Jiading District of Shanghai as examples, the paper applies these indicators to evaluate the senior-friendliness of service facilities in living circles for residential communities. The results show that welfare facilities for the elderly and recreational facilities are greatly needed, and the suitability of basic guaranteed facilities and the convenience of quality enhancement facilities have significant urban-rural differences. It is also found that service facilities in residential communities near the boundaries of administrative divisions have the lowest availability of facilities; residential communities in non-core suburban areas are in urgent need for access to basic guaranteed facilities. Therefore, locations of new facilities to be constructed should prioritize areas with limited availability of both basic guaranteed facilities and quality enhancement facilities. **DOI:** 10.13813/j.cn11-5141/u.2022.0405-en

Keywords: living circles; residential communities; service facilities; evaluation of senior-friendliness; weighted kernel density; basic guaranteed facilities; quality enhancement facilities; Shanghai

0 Introduction

Aging is becoming an increasingly severe problem in China. It was confirmed at the fifth plenary session of the 19th CPC National Congress held in 2020 that a sound basic old-age service network should be in place, and the Chinese government should develop an old-age service network that coordinates home, community, and facility care and combines medical care with health preservation [1]. As elderly people's physical function deteriorates, their demands for old-age service facilities are growing. The construction of senior-friendly living circles should not be only based on the 15-minute life circle planning for ordinary adults. Urgent measures should be taken to address the supply-demand conflict caused by the absence of facilities for the elderly in conventional residential community planning [2]. Research on *Hangzhou Neighborhood Center Planning* compiled by Hangzhou Bureau of Planning and Natural Resources reveals that the elderly are the main users of service facilities in the living circle. Senior-friendliness construction within living circles stresses the idea of serving elderly people's daily life, which implies that facilities within living circles do not have to be all-encompassing. Instead, facilities should be centered around areas where the elderly gather and live, and they should mainly meet the fundamental demands of the elderly while improving their living quality. Due regard should be given to both equity and efficiency of the facilities [3]. Current facility evaluation methods usually use coverage and kernel density indicators to assess large areas, and they neglect that the construction of facilities should be centered on residential areas and serve the needs of residents [4–6].

In this paper, we put forward a method for senior-friendliness evaluation of service facilities in living circles of residential communities, and the method has considered elderly people's demands. According to elderly people's

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walking capability and activity features, elderly people's activity range in living circles of residential communities is redefined. Then, facilities are categorized into basic guaranteed facilities and quality enhancement facilities, and facility supply-demand matching is explored. Comparable senior-friendliness evaluation indicators for service facilities are put forward to steer senior-friendliness construction in living circles for residential communities, so as to better meet the need of the aging society.

1 Elderly people's activity range and service facility utilization features

1.1 Elderly people's daily activity range

In the exploration of living circle construction, comprehensive Chinese residents' average walking pace is used for deduction. In general, an 800–1 000 m distance within 15 minutes by adults on foot is defined as the delineation standard for the activity range within the living circle [7]. In a society where the degree of population aging is high, and the growth rate is fast, the activity range of elderly people in living circles of residential communities should be redefined in accordance with their walking capability and activity characteristics [8]. Walking is the most common way for the elderly when they go out [9]. Walking capability mirrors elderly people's motion capability to a large extent.

1) Walking speed

By analyzing the walking data of 1 882 people in Beijing through videos, Ma et al. [10] found that the average walking speed of the elderly is 1.04 $m \cdot s^{-1}$. Cai et al. [11] studied the walking speed of healthy elderly people both in China and abroad and found that the walking speed of elderly people is 1.068 $m \cdot s^{-1}$ through Meta-analysis. According to the chapter on human body scale in the first volume of *Architectural Design Data Set (Third Edition)*, the comprehensive average walking speed of Chinese residents (including teenagers and middle-aged and elderly people) is 1.22 $m \cdot s^{-1}$, which is in stark contrast with that of the elderly [12–13].

2) Walking duration

Huang et al. [14] conducted field research on the elderly in four areas of the center of Shanghai and found that the average travel time of the elderly decreased by 64% (only 11.8 min) compared with that of the whole population. Li et al. [15] discussed the attenuation law of walking time spent in getting to facilities according to the difference in the walking ability of the elderly. They found that when the elderly went to important facilities such as food markets and fruit shops, their walking ability decreased by about 70% after walking for 10 minutes and by about 90% after walking for 15 minutes. Through multiple iterative clustering, Li et al. [16] found that the one-way travel time of the elderly is only 7.5–10.0 min.

3) Walking distance

Mao et al. [17] believed that the radius of the basic living circle of the elderly was small, about 180–220 m, which was consistent with the five-minute walking distance of the elderly. In general, the radius of long-term activities and the familiar living circle of the elderly was less than 450 m. According to Zhang [18], elderly people mainly hung out around their communities, with a small activity radius. In addition, they usually travel on foot or by bus. Wu et al. [19] took 1.04 $m \cdot s^{-1}$ as the average walking speed of the elderly (> 60 years old) and 11.8 minutes as the average walking duration of the elderly, and thus they calculated that the average travel distance of the elderly was about 740 m. Since the physical function of the elderly would further decay, they suggested that 700 m should be taken as the research scope of the senior-friendliness of the living circle.

Since travel time has a greater impact than travel distance on travel [17], this paper takes ten-minute walking as the standard to divide the living circle of the elderly and five-minute walking as the standard to divide the core layer of the living circle. Furthermore,1.05 $m \cdot s^{-1}$ was taken as the average walking speed of the elderly, and it was calculated that the ranges of the living circle and the core layer of the living circle of the elderly were 630 m and 315 m, respectively. This conclusion is also close to the corresponding distance of five-minute (200–300 m) and ten-minute (500 m) living circle facility layers in *Shanghai Planning Guidance of 15-Minute Community-Life Circle (Trial)* (hereinafter referred to as the *Guidance*).

1.2 Characteristics of the utilization of service facilities in the living circles of the elderly

The physical function, perception, and cognitive capabilities of the elderly will inevitably degrade over time. Meanwhile, without direct involvement in social production, the elderly have more time at their own disposal. So, their travel is characterized by leisure and a slow pace, and they are major participants in daily society life [20–21]. Therefore, it is of great significance to study the utilization features of service facilities in the living circle of the elderly, so as to allocate corresponding facilities rationally.

Requirements for the construction of facilities for the elderly have been stipulated in relevant specifications. It is clearly stated in the *Guidance* that the daily facilities for the elderly shall be centered around the food markets and be close to facilities such as greenbelts, small-scale commerce centers, schools, and training institutions. For facilities that are frequently used by the elderly and children, such as kindergartens, parks, pension facilities, and food markets, they should be reached within five minutes on foot. Attention should be paid to shortening the distance for the elderly and children in getting to reading rooms and physical training sites. In terms of facilities for the elderly, day-care centers should be reached within ten minutes on foot, and recreation

rooms for the elderly should be reached within five minutes on foot [4]. It is specified in the *Standard for Urban ResidentialArea Planning and Design* (GB 50180—2018) (hereinafter referred to as the *Standard*) that among the supporting facilities of residential communities that can be reached within five minutes on foot, community service stations, recreation centers (including recreation centers for teenagers and the elderly), day-care centers for the elderly, community health service centers, community commercial outlets, and other service facilities should be planned together and built jointly, so as to form a comprehensive community service center [22]. According to the *Code for Planning of City and Town Facilities for the aged (GB 50437—2007) (2018)* (hereinafter referred to as the *Code*), in the system for the hierarchical allocation and construction of facilities for the elderly, residential areas (towns) shall be equipped with nursing homes, activity centers, service centers (stations), apartments, schools, and care centers for the elderly. Communities shall be equipped with recreation centers, service centers (stations), and care centers for the elderly. The layout of facilities for the elderly shall conform to the distribution characteristics of the local elderly people, and these facilities should be close to areas densely populated by the aged [23].

Many experts also carried out concrete research in line with standards and specifications. Through questionnaire and comprehensive transportation survey data, Huang et al. [14] found that trips for shopping accounted for the largest proportion among the elderly of all ages, and the proportion of trips for medical examination increased with the age (see Fig. 1). Based on the *Code for Design of Buildings for Elderly Persons (JGJ 122—99)* and survey results, Li et al. [15] divided the walking capability of the elderly into five categories. They found that elderly people's facility utilization frequency decreased gradually, and the demands for facility types decreased as their walking capability reduced. Food markets, parks, green belts, and clinics are facilities visited by the elderly most frequently. Through the survey, Li [24] found that the elderly of all ages mainly visited shopping facilities such as food markets and supermarkets. Usually, the elderly aged 60–69 years old actively took part in community activities and frequently used leisure facilities such as parks and community recreation centers, while the elderly aged over 70 years old frequently visited nursing facilities.

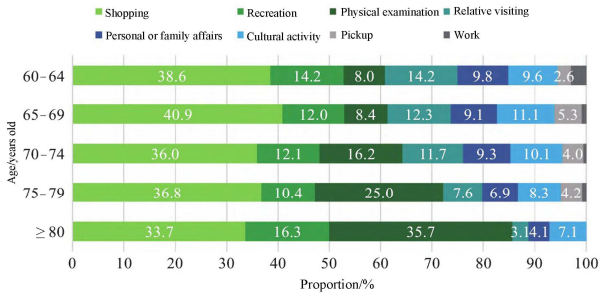

Fig. 1 Changes in travel purposes of the elderly with age.Source: Literature [14].

Our study targets the elderly aged above 60 years old. According to the classification system of service facilities in living circles extracted from the *Guidance*, standards, specifications, and academic research conclusions, relevant facilities should be arranged in places that the elderly in the living circles can reach on foot within 5–10 minutes. Referring to the three-level classification of facilities for the elderly in terms of importance[15], we come up with a service facility system in the living circle for the elderly in this paper (see Table 1).

2 Study data

Open source data have many advantages such as wide coverage, high spatial precision, and strong availability, which sheds new lights on studying residential districts. In this paper, we employ an interface to obtain data including point of interests (POI), area of interests (AOI), road network, population raster, etc., and integrate multi-source data to provide support for evaluating the senior-friendliness of service facilities in living circles.

1) POI data

POI refers to a geographical entity abstracted as a point in a geographic information system. It can be a community, a venue, or a store. POI has advantages in terms of facility spatial analysis because of its large sample volume, high spatial precision, abundant information, simple extraction, and high data quality. The POI data used in this paper comes from Gaode Map. 28 types of POI are extracted based on facility keywords.

2) AOI data

AOI refers to regional geographical entities in map data, which can be understood as POI with geographical boundaries. The AOI data used in this paper comes from Baidu Map. AOI information of residential communities is obtained and then connected with POI data according to AOI spatial distribution.

3) Road network data

Road network refers to the network structure organized by roads with different functions, grades, and locations within a city, and the network structure is constructed in line with a certain density and appropriate form. Internet map service providers offer free map application development interface (API) to users. Web interface and walking path planning algorithm are employed to solve the walking distance along the route network. In this paper, the walking distance between residential communities and facilities is calculated through the API function of Gaode Map.

4) Population raster data

The WorldPop research team from University of Southampton in the UK used the large-scale data processing capabilities of Microsoft Azure to accurately map demographic data [25]. The spatial resolution of the WorldPop population

Table 1 System of service facilities in living circles for the elderly

Indicator system in *Guidance*				Standards, specifications, and research suggestions for senior-friendly facilities				System generalized in this paper	
Category	Item	POI	Walking duration	*Guidance*	*Standard*	*Code*	Research	Walking duration	Importance
Basic guaranteed facility				Basic guaranteed facility		Facilities that shall be built		Basic guaranteed facility	
Culture	Community culture center	Cultural activity center, IT center, museum, exhibition room, art gallery, library, science & technology museum, planetarium, and cultural palace	15 min						
Education	Kindergarten	Kindergarten	5 min	5 min			Moderately frequent utilization	5 min	★
	Primary school	Primary school	10 min				Moderately frequent utilization	10 min	★
	Junior & senior high school	Middle school	15 min						
Medical treatment	Community health service center	Comprehensive hospital, specialized hospital, and community health service center	15 min						
	Health service station	Clinic and health service center	10 min		5 min		Highly frequent utilization	5 min	★★★
Welfare for the elderly	Community nursing home	Nursing home, gerocomium, apartment for the elderly, and sanatorium		5 min		Residential level		5 min	★
	Day-care center	Nursing home, day-care center, and service center for the elderly	10 min	5 min	5 min	Residential level	Moderately frequent utilization	10 min	★
	Activity room for the elderly	Activity room for the elderly	5 min	5 min	5 min	Residential level	Moderately frequent utilization	5 min	★★
	Worker's sanatorium and health service center	Worker's sanatorium and health service center							
Sports	Comprehensive fitness center	Comprehensive gymnasium	15 min						
	Swimming pool	Swimming pool	15 min						
	Sports ground	Football field, basketball court, tennis court, badminton court, and table tennis court	15 min						
Business	Indoor food market	Food market and agricultural and sideline food market	10 min	5 min to the core			Highly frequent utilization	5 min	★★★
	Small business center	Supermarket and convenience store	10 min				Highly frequent utilization	5 min	★★★
Recreation	Small-scale public space	Public space, square, and park	5 min	5 min			Highly frequent utilization	5 min	★★★
Quality enhancement facility				Quality enhancement facility		Facilities that shall be built		Quality enhancement facility	
Culture	Cultural activity room	Chess and card room, reading room, and cultural activity room	10 min		5 min			5 min	★★
Education	Community school	School and college for the elderly				Residential level	Moderately frequent utilization	10 min	★★
	Child care	Baby care and child-care center	10 min						
Sports	Fitness site	Indoor (outdoor) fitness site and fitness center	5 min					5 min	★★★
Business	Community canteen	Dining room and community canteen	10 min						
	Life service center	Life service center, repair service, household service, laundry, grocery store, express station, and tailor store	5 min		5 min				

data set reaches 100 m, displaying high spatial resolution accuracy and population fitting accuracy. In this paper, WorldPop 2019 China population density raster data is used to calculate the population in residential communities.

3 Senior-friendliness evaluation methods for service facilities

3.1 Evaluation of the suitability of basic guaranteed facilities

1) Comprehensive weighted kernel density estimation of basic guaranteed facilities

Based on a specific search radius, kernel density analysis calculates the density of elements in the surrounding fields through the orthogonal kernel function. The results can clearly present the distribution characteristics of a certain type of service facility in the living circle of residential communities. The linear weighting method is employed to weigh the calculation results of kernel density of different types of service facilities in terms of importance, and the comprehensive weighted kernel density of basic guaranteed facilities in the living circle can be obtained. The formula is as follows [26–27]:

$$D_{i,j}=\frac{1}{r^2}\sum_{k=1}^{n}\left[\frac{3}{\pi}\left(1-\left(\frac{d_{i,jk}}{r}\right)^2\right)^2\right],\ k\in C_{i,j}\ ,$$

$$D_i=\sum_{j=1}^{m}D_{i,j}W_j\ ,$$

where $D_{i,j}$ denotes the kernel density of class j basic guaranteed facilities in the living circles of residential community i, with a unit ofnumber·m^{-2}; r denotes the search radius, with a unit of m. In this paper, the ten-minute living circle corresponds to a walking distance of 630 m, or the five-minute living circle corresponds to a walking distance of 315 m; k denotes a specific facility of class j basic guaranteed facilities; $d_{i,jk}$ denotes the walking distance between residential community i and facility k in the class j basic guaranteed facilities, with a unit of m; $C_{i,j}$ denotes the living circles for the elderly from residential community i to class j basic guaranteed facilities; D_i denotes the comprehensive weighted kernel density of basic guaranteed facilities in residential community i, with a unit ofnumber·m^{-2}; W_j denotes the importance weight of class j basic guaranteed facilities.

2) Facility suitability evaluation

Sound living circle calls for suitable supply and demand of facilities. If the facilities of living circles in communities are improved, proper public service facility standards should also be established in accordance with the demographic structure [28]. Facility supply-demand matching is calculated by the ratio of the comprehensive weighted kernel density of basic guaranteed facilities to the number of the elderly in residential communities. The average value of the supply-demand ratio is allowed to be adjusted by ±50%. In the end, a suitable range for average facility volume is defined. The formula is [29]

$$R_{i,j}=\frac{D_{i,j}}{P_i},\quad R_i=\frac{D_i}{P_i},$$

$$BG_{i,j}=\begin{cases}\text{Moderate suitability} & R_{i,j}\in G_j\\ \text{High suitability} & R_{i,j}>G_j\\ \text{Low suitability} & R_{i,j}<G_j\\ \text{No facility} & R_{i,j}=0\end{cases},$$

$$BG_i=\begin{cases}\text{Moderate suitability} & R_i\in G\\ \text{High suitability} & R_i>G\\ \text{Low suitability} & R_i<G\\ \text{No facility} & R_i=0\end{cases},$$

where $R_{i,j}$ denotes the supply-demand ratio of class j basic guaranteed facilities within the living circles of residential community i; P_i denotes the number of the elderly within residential community i; R_i denotes the comprehensive supply-demand ratio of basic guaranteed facilities within residential community i; $BG_{i,j}$ denotes the evaluation result of the suitability of class j basic guaranteed facilities within the living circle of residential community i; G_j denotes the suitability range of class j basic guaranteed facilities; BG_i denotes the comprehensive evaluation result of the suitability of class I basic guaranteed facilities in residential community i; G denotes the suitability range of the comprehensive evaluation of basic guaranteed facilities.

3.2 Convenience evaluation of quality enhancement facilities

Quality enhancement facilities are an additional requirement for public facility construction after basic guaranteed facilities are ensured. So, the number of quality enhancement facilities in the living circles of residential communities can present convenience. If there is no quality enhancement facility within the living circle of residential communities, there is no convenience. If only one quality enhancement facility is available, the convenience is low. When two or three facilities are available, the convenience can be moderate, and when more than four facilities are available, the convenience is high [30]. The convenience evaluation of comprehensive facilities is based on that of the classified facilities, so when all facilities have no or low convenience, the convenience evaluation of comprehensive facilities is also low. The same is true of the other two cases. The formula for calculating convenience is

$$S_{i,j}=\begin{cases}COUNT(k), & k\in C_{i,j}\\ 0, & \text{Others}\end{cases},\quad S_i=\sum_j S_{i,j}$$

$$QI_{i,j}=\begin{cases}\text{High} & S_{i,j}\geq 4\\ \text{Moderate} & 1<S_{i,j}<4\\ \text{Low} & S_{i,j}=1\\ \text{No} & S_{i,j}=0\end{cases},\quad QI_i=\begin{cases}\text{High} & S_i\geq 12\\ \text{Moderate} & 3<S_i<12\\ \text{Low} & S_i=3\\ \text{No} & S_i=0\end{cases},$$

where $S_{i,j}$ denotes the number of class j quality enhancement facilities in the living circles of residential community i; S_i denotes the total number of quality enhancement facilities in residential community i; $QI_{i,j}$ denotes the evaluation results of the convenience of class j quality enhancement facilities in the living circles of residential community i; class j facilities involve culture (cultural activity room), education (community school), and sports (fitness site) aspects; QI_i denotes the comprehensive evaluation results of the convenience of quality enhancement facilities in residential community i.

3.3 Relevancy evaluation of the spatial distribution of facilities

The relevancy evaluation of facility spatial layout consists of the evaluation of spatial self-correlation of facilities and that of inter-facility correlation. Spatial self-correlation evaluation is a statistical test method used to analyze the spatial clustering characteristics of evaluation indicators. It can identify whether the comprehensive weighted kernel density of basic guaranteed facilities and the number of quality enhancement facilities in the living circle are aggregated, so as to identify the areas that need to be constructed urgently. Inter-facility correlation evaluation uses a correlation coefficient to measure the degree of correlation among variables. It can be used to judge whether the comprehensive weighted kernel density of basic guaranteed facilities in the living circle is related to the distribution of high and low values of quality enhancement facilities, so as to identify areas with limited availability of both basic guaranteed facilities and quality enhancement facilities.

3.3.1 Evaluation of facility spatial self-correlation

Facility spatial self-correlation should be evaluated separately in terms of the above-mentioned comprehensive weighted kernel density of basic guaranteed facilities and quantity of quality enhancement facilities. Global Moran's I is an important indicator to measure spatial correlation. After variance normalization, the value ranges from −1.0–1.0. Moran's I > 0 indicates a positive spatial correlation. A large value is often accompanied by an obvious correlation. When Moran's I < 0, it indicates a negative spatial correlation, and a small value implies a large spatial difference. When Moran's I = 0, it indicates that the space is stochastic. The formula is as follows:

$$I = \frac{n}{S_0} \times \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2},$$

$$S_0 = \sum_{i=1}^{n}\sum_{j=1}^{n} w_{i,j},$$

where I denotes the global Moran index; n denotes the total number of elements; S_0 denotes the aggregation of all spatial weights; $w_{i,j}$ denotes the spatial weight between elements i and j. In this paper, it denotes the comprehensive weighted kernel density of basic guaranteed facilities and the number of quality enhancement facilities; z_i denotes the deviation between the attribute of element i and its mean value; z_j denotes the deviation between the attribute of element j and its mean value.

3.3.2 Inter-facility correlation evaluation

The evaluation of the correlation between the comprehensive weighted kernel density of basic guaranteed facilities and the number of quality enhancement facilities is carried out. Kendall correlation coefficient [30–31] is a statistical value to measure the correlation between two ordered categorical variables. The correlation value ranges from −1 to 1. If the value is closer to 1, the correlation between two random variables is strong. For two random variables X and Y, $X = \{x_1, x_2, ..., x_n\}$, $Y = \{y_1, y_2, ..., y_n\}$. The two variables both contain n elements. In X and Y, there are C_n^2 groups of element pairs (x_i, x_j) and (y_i, y_j), with $i \neq j$, $1 \leq i$, and $j \leq n$. The formula is as follows:

$$\tau = \frac{N_1 - N_2}{\sqrt{(N_0 - N_3) \times (N_0 - N_4)}},$$

where τ denotes the Kendall correlation coefficient; N_1 denotes the number of positively correlated element pairs ($x_i > x_j$ and $y_i > y_j$, $x_i < x_j$ and $y_i < y_j$) in X and Y; N_2 represents the number of negatively correlated element pairs ($x_i > x_j$ and $y_i < y_j$, $x_i < x_j$ and $y_i > y_j$) in X and Y; N_0 is the total number of element pairs, and $N_0 = C_n^2$; N_3 refers to the number of identical element pairs ($x_i = x_j$) in X; N_4 is the number of identical element pairs ($y_i = y_j$) in Y.

4 Practice in Huangpu District and Jiading District of Shanghai

4.1 Selection of study areas

Shanghai is the first city in China ushering in an aging society. Its aging degree decreases from the downtown to the suburban area, which shows a clearly imbalanced distribution between urban and rural areas. To make an urban-rural comparison, we select Huangpu District located in the downtown area within the outer ring, Jiading industrial zone, Jiading Town sub-district, Xinchenglu sub-district, and Juyuanxinqu sub-district located in the central Jiading District outside the outer ring as our research objects (Fig. 2). In total, there are 638 residential communities in Huangpu District and 189 residential communities in four sub-districts of central Jiading District.

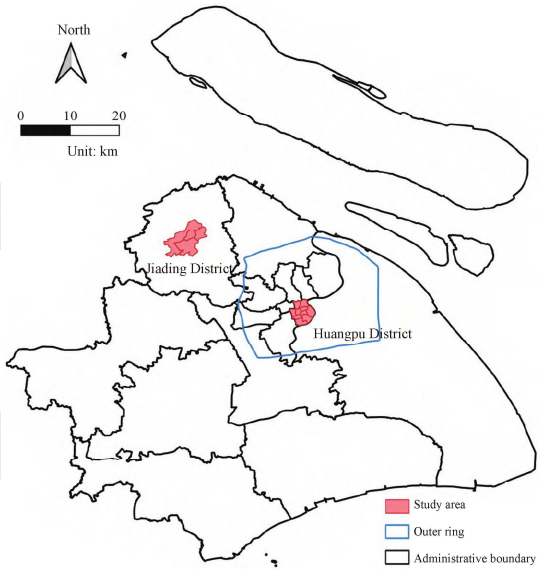

Fig. 2 Location of research objects

4.2 Living circles of the elderly

In line with elderly people's travel demands and characteristics, we design living circles for the elderly in terms of two levels, namely, a ten-minute walking distance range and a five-minute walking distance.

1) Data pre-processing

We download POI and AOI data of residential communities within the scope of the research objects. Then, we first delete duplicate and invalid items and then link POI and AOI data according to spatial distribution. Since AOI data division is rough, POI data are allowed to be associated with AOI data in accordance with the many-to-one rule. Finally, elements that cannot be associated are deleted.

2) Calculation of living circles of the elderly

The living circles shall start with the boundaries of the

community. First, the time spent in walking by residents within the community shall be removed. Specifically, the virtual radius R_0 is calculated by the geometric area of the AOI of the community. Elderly people's ten-minute walking distance and five-minute walking distance are expressed as $R_{10} = R_0 + 630$ m and $R_5 = R_0 + 315$ m, respectively. With a residential community in the Bund sub-district of Huangpu District as an example (Fig. 3), the virtual radius of the community is 80 m, while the calculated average length of the actual route from each residential building to the entrance and exit of the community is 78 m, with an error of 2.5%, which thus verifies the effectiveness of the method.

Fig. 3 Range of living circles in a residential community with the elderly

4.3 Calculation of the number of the elderly

According to the existing data, the number of the elderly in each residential community is calculated, and it serves as the facility demand side.

1) Calculation of the proportion of the elderly at the sub-district level

Since it is impossible to obtain sub-district-level demographic structure data from the seventh national population census conducted in 2020, we first collect township-level demographic structure data from the sixth national population census conducted in 2010. Then, according to the number of the elderly, we calculate their proportion. By dividing the proportion of the elderly at the township level in the seventh national population census by that in the sixth national population census, we come up with the increase coefficient of the elderly and then calculate the proportion of the elderly in each sub-district in 2020 (Table 2).

2) Calculation of the number of people in residential communities

WorldPop 2019 China's regional population density raster data and QGIS3.6 sub-region statistic function are employed to calculate the sum of raster values within the AOI of the residential communities. The sum is treated as the number of people in the residential communities. At last, the number of the elderly in the residential communities is obtained by multiplying the number of people in the residential communities and the proportion of the elderly in sub-districts that the communities belong to (Fig. 4)

Table 2 Proportion of the elderly in sub-districts of the study area %

Administrative unit	Proportion of the elderly	
	2010	2020
Huangpu District	24	40
Laoximen sub-district	13	31
Bansongyuan road sub-district	14	33
Dapuqiao sub-district	15	35
Wuliqiao sub-district	16	36
Dongjiadu sub-district	14	33
Yuyuan sub-district	12	30
Huaihaizhonglu sub-district	15	35
Ruijin Erlu sub-district	21	45
Bund sub-district	13	33
Nanjingdonglu sub-district	15	35
Central Jiading District	24	34
Jiading Town sub-district	13	37
Jiading industrial zone	7	28
Juyuanxinqu sub-district	6	26
Xinchenglu sub-district	7	29

1) Data are missing. It is calculated according to similar sub-districts. Data source: the sixth and the seven national census data.

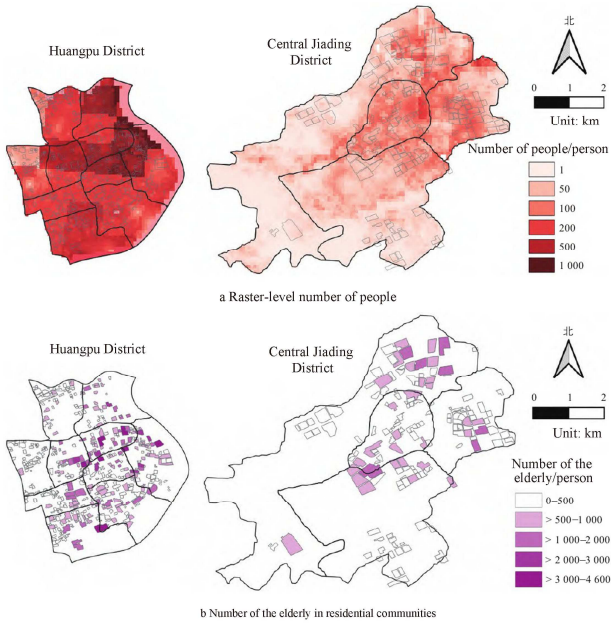

Fig. 4 Raster-level number of people and the number of the elderly in residential communities in the study area

Note: The raster resolution is three radians (about 100 m at the equator).

4.4 Senior-friendliness evaluation of service facilities in living circles

4.4.1 Evaluation of the suitability of basic guaranteed facilities

1) Suitability proportion of basic guaranteed facilities

As Table 3 shows, 23% of communities in Huangpu Dis-

trict are highly equipped with basic guaranteed facilities, and 29% of communities are suitably equipped with these facilities. All communities have these facilities to some extent. However, 9% of communities in central Jiading District are suitably or highly equipped with basic guaranteed facilities, and 19% of communities have no facilities. Therefore, there is a prominent urban-rural difference in terms of facility layout.

Two study areas are severely lacking in a special facility. Specifically, 96% and 97% of residential communities in central Jiading District have no community nursing home or activity room for the elderly, which indicates that most elderly people have difficulty in gaining access to services for the elderly within their living circles. Therefore, priority should be given to the construction of basic guaranteed services in these areas. According to the standards and specifications stated above, the activity room for the elderly should be reached by the elderly on foot within five minutes, and it should be emphasized during implementation. However, there is no clear stipulation in standards or specifications for a community nursing home. When the number of community nursing homes is calculated in terms of a ten-minute walking distance, the proportion of communities in Huangpu District and central Jiading District without basic guaranteed services decreases to 66% and 71%, respectively. Therefore, standards in this regard should be set up. There is a marked difference between the two areas in terms of commercial facilities, especially in the availability of convenience stores and supermarkets. It shows that commercial facility layout is driven by economic interests. As a result, commercial facilities tend to be built in areas with high demand, which results in significant urban-rural disparity.

2) Spatial distribution of facility suitability

As Fig. 5 shows, medical facilities and welfare facilities for the elderly in the two study areas are mainly absent in the boundaries of administrative divisions, which may be attributed to the lowest influence of administrative boundaries. Of all the basic guaranteed facilities for the elderly in Huangpu District, recreational facilities are in serious shortage. Areas with such phenomenon are concentrated, but the range is extensive, which can be attributed to tight land resources and insufficient public spaces. By analyzing the spatial distribution of various types of facilities, we can develop a clear picture of communities without basic guaranteed facilities, so as to scientifically select a site to build new facilities.

4.4.2 Convenience evaluation of quality enhancement facilities

In terms of convenience evaluation of quality enhancement facilities, the number of facilities with convenience is weighed. A heat map is employed to better present areas with facilities in high availability and low availability (Fig. 6). High convenience means that facilities are mainly distributed in a certain area. Overall, the elderly in 95% of residential communities in Huangpu District can gain access to quality enhancement facilities. High convenience is found in southwestern and northeastern areas, and the convenience degree gradually decreases in the western part along the coastal area. As for central Jiading District, only the core area of sub-districts has a high facility convenience degree. 40% of communities have no access to quality enhancement facilities. The convenience of cultural facilities in Huangpu District gradually decreases along the coastal line, which may be attributed to the presence of plentiful cultural venues along the coastal scenery area of the Huangpu River.

4.4.3 Relevancy evaluation of the spatial distribution of facilities

1) Spatial self-correlation of facilities

The evaluation results of the suitability of basic guaranteed facilities and convenience of quality enhancement facilities in two study areas in Huangpu District show agglomeration. The convenience of quality enhancement

Table 3 Proportion of suitability of basic guaranteed facilities %

Study object	Suitability	Basic guaranteed facility									
		Education		Medical treatment	Welfare for the elderly			Business		Recreation	Total
		Kindergarten	Primary school	Health service station	Community nursing home	Day-care center	Activity room for the elderly	Indoor food market	Small business center	Small-scale public space	
Huangpu District	No facility	49	9	28	76	36	77	23	1	50	0
	Low suitability	24	41	34	0	26	0	0	0	0	48
	Moderate suitability	11	31	23	13	17	11	58	76	33	29
	High suitability	16	19	15	11	21	12	19	23	17	23
Central Jiading District	No facility	74	52	69	96	78	97	49	91	73	19
	Low suitability	19	34	16	2	7	0	0	0	0	72
	Moderate suitability	2	9	7	1	8	1	44	7	22	6
	High suitability	5	5	8	1	7	2	7	2	5	3

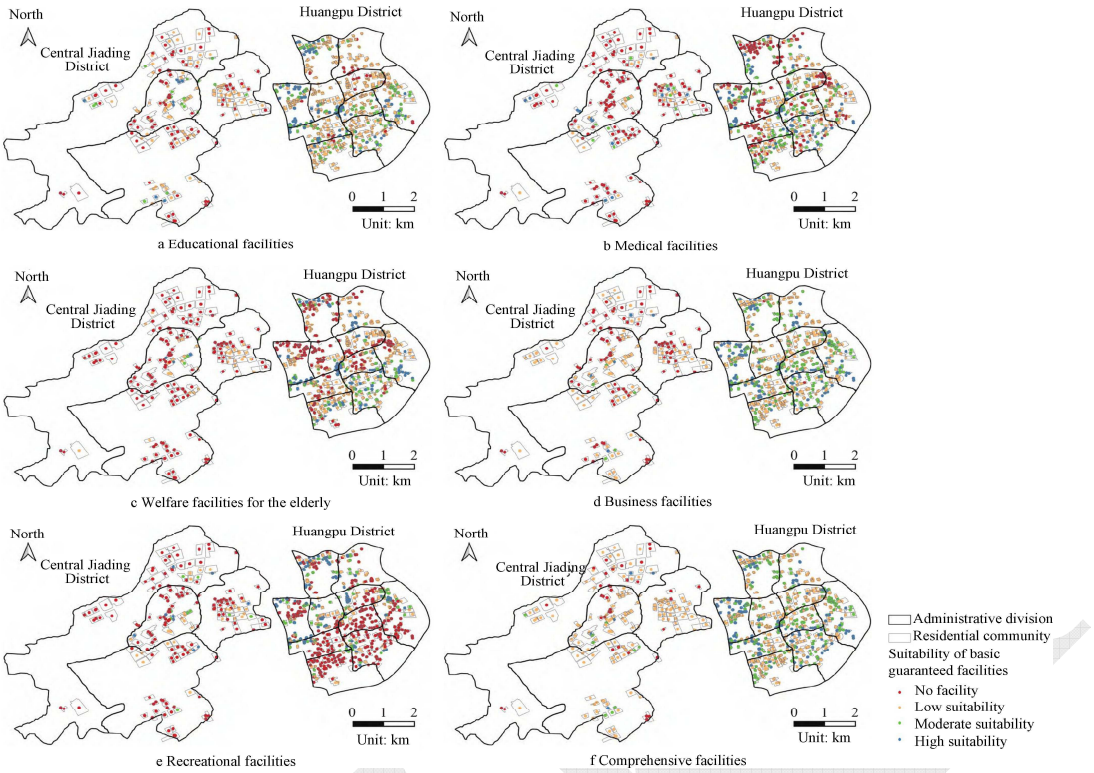

Fig. 5 Spatial distribution of suitability of basic guaranteed facilities

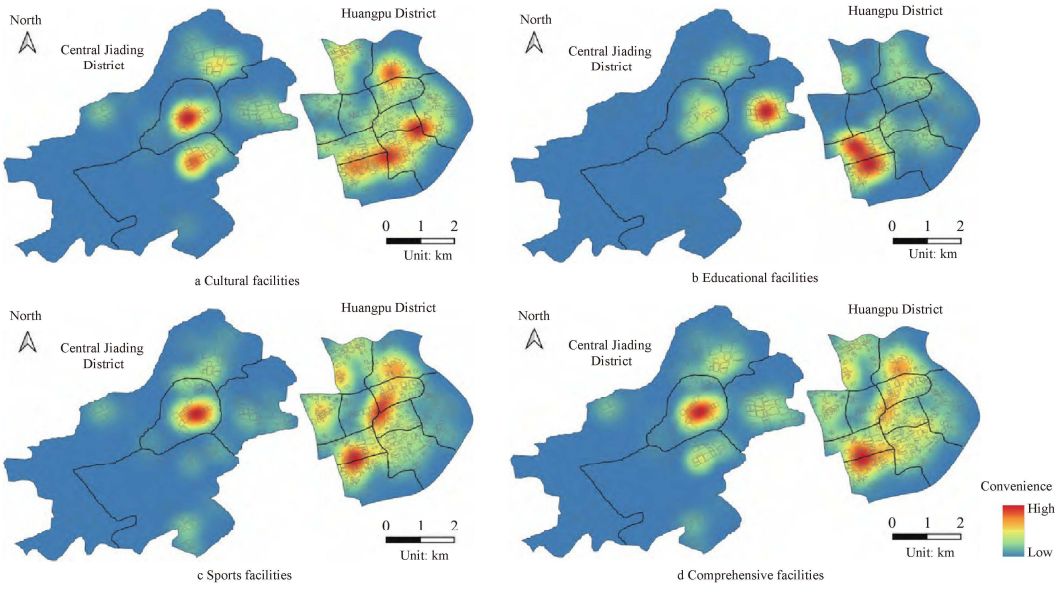

Fig. 6 Kernel density of convenience of quality enhancement facilities

facilities in Huangpu District shows the strongest agglomeration effect, while the suitability distribution of basic guaranteed facilities in Jiading District is relatively stochastic (Fig. 7). In Huangpu District, these two types of facilities show an obvious spatial agglomeration effect. 34% of residential communities show strong enhancement facility convenience and high basic guaranteed facility suitability. 18% of residential communities located along the river in the east and inland in the west show weak enhancement facility convenience and low basic guaranteed facility suitability, which makes them the priority for building new facilities. 80% of residential communities in central Jiading District show weak enhancement facility convenience and low basic guaranteed facility suitability. However, their spatial agglomeration is stochastic, which may be attributed to the dispersed spatial distribution of residential communities in suburban areas.

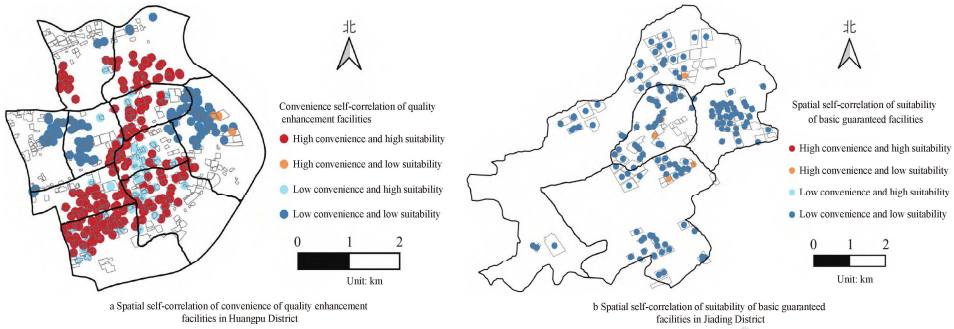

Fig. 7 Self-correlation evaluation on integrated facility space

2) Inter-facility correlation

According to the calculation, the value of the Kendall correlation coefficient is 0.202, and the correlation is significant at the 0.01 level, which indicates that the comprehensive weighted kernel density of basic guaranteed facilities is in a positive correlation with the number of quality enhancement facilities. The two types of facilities are divided into four correlated areas in line with the lower limit of suitability range of comprehensive evaluation of basic guaranteed facilities (G) and the low degree of convenience of quality enhancement facilities. Then, a scatter plot is drawn (Fig. 8). Overall, residential communities in Huangpu District have high enhancement facility convenience and high basic guaranteed facility suitability, while residential communities in central Jiading District have weak enhancement facility convenience and low basic guaranteed facility suitability, which shows a significant difference between urban and rural areas.

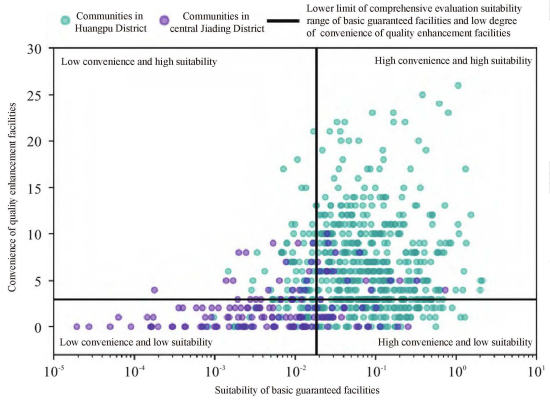

Fig. 8 Scatter plot of spatial distribution relevancy of basic guaranteed facilities and quality enhancement facilities

The spatial distribution relevancy of basic guaranteed facilities and quality enhancement facilities is shown in Fig. 9. The layout of facilities in Huangpu District is mixed. Residential communities with low availability of both basic guaranteed facilities and quality enhancement facilities and those with low enhancement facility convenience and high basic guaranteed facility suitability can use facilities from neighboring areas. Only the core areas of residential communities in central Jiading District show high availability of both basic guaranteed facilities and quality enhancement facilities. In contrast, surrounding areas have limited availability of both basic guaranteed facilities and quality enhancement facilities, so priority should be given to these areas to make them equipped with relevant facilities.

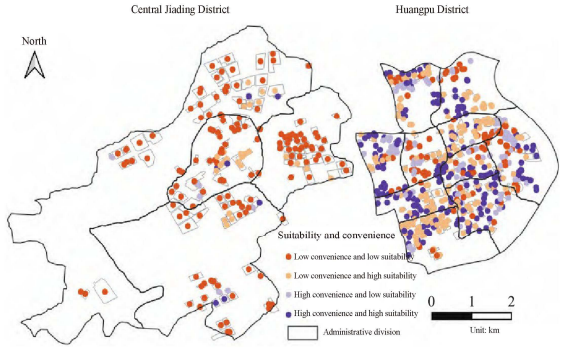

Fig. 9 Spatial distribution relevancy of basic guaranteed facilities and quality enhancement facilities

5 Conclusion

Based on multi-source data and elderly people's activity range and facility utilization features, we propose indicators such as the suitability of basic guaranteed facilities in living circles, convenience of quality enhancement facilities, and relevancy of spatial distribution of facilities and carry out the senior-friendliness evaluation of facilities in living circles of residential communities in Shanghai by taking Huangpu District and central Jiading District as cases.

According to the research findings, as demands for senior services grow in an aging society, welfare facilities for the elderly and recreational facilities such as community nursing homes and activity rooms for the elderly are severely inadequate. There are noticeable urban-rural differences in the senior-friendliness of service facilities in living circles. Quality enhancement facilities are widely introduced in residential communities in downtown areas, while a large number of suburban residential communities still have no adequate basic service facilities. Apart from implementation, the standard is another problem contributing to the low suitability of basic guaranteed facilities. Specifically, there are ambiguous,

inconsistent, and unsound standards or specifications. All these standards and specifications need to be amended.

In this paper, we put forward an evaluation method that considers the supply-demand relationship, places facilities under different categories, and balances both equity and efficiency. The method can effectively identify the problems in the number of basic guaranteed facilities and quality enhancement facilities and their spatial distribution, thus offering suggestions on the site selection of relevant service facilities. According to evaluation results, suburban areas should be prioritized, especially the non-sub-district core areas in the suburbs, and basic guaranteed facilities should be built in those areas. The construction shall take into account concrete conditions in line with the suitability evaluation of facilities. In addition, special attention should be paid to residential communities within the boundaries of administrative divisions. The quality enhancement facilities should be first introduced in areas with limited availability of both basic guaranteed facilities and quality enhancement facilities.

The evaluation results can guide the planning and construction of service facilities in living circles, so as to improve the senior-friendliness of service facilities and guarantee elderly people's daily life in an aging society. However, we have not come up with precise data on the actual number of the elderly in residential communities and developed a full picture of the demands for service facilities in living circles of elderly people of different ages. Furthermore, we fail to take into consideration the problem of the narrowing activity range of elderly people caused by environmental unfriendliness, which will be a new research focus in the future.

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