Investigating walking accessibility to recreational amenities for elderly people in Nanjing, China

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Abstract

Taking into account the rapidly aging demographic landscape in China, securing elderly's right to participate in society has become an urgent challenge. Geographical access to urban amenities is known to influence social participation and integration. However, the application of accessibility analysis to elderly population in China has received little attention to date. This study examines the walking accessibility to recreational amenities for older adults in the Chinese context with an explicit focus on equity. Building on empirically-based estimates of a cumulative opportunity approach, we calculate the levels of accessibility at the traffic analysis zone level, evaluate how accessibility varies across age cohorts, and present the distribution of accessibility across zones. To this end, we draw on the 2015 Nanjing Travel Survey and the city's GIS database. Instead of assuming a fixed threshold, this paper applies a spatial expansion model to allow for person- and location-specific walking distances to measure accessibility. The spatial disparities in access to recreational amenities are evaluated using the notion of vertical equity for identifying areas that are better-off or worse-off. Our results show pronounced distributional effects of current land-use and transportation policies for different age cohorts. In particular, elderly people experience lower accessibility to chess/card rooms and urban parks than their younger counterparts. The empirical evidence in this research can inform planning and policy interventions and feed current scientific debates on the role of accessibility in addressing social inclusion for an age-friendly society.

Keywords: Aging population; Walking accessibility; Recreational amenities; Adaptive threshold; Vertical equity; Spatial expansion model

1 Introduction

Demographic aging is now a prevalent societal phenomenon across the world. In 2017, 12% of the world population was aged 60 years or over; by 2050 this figure is anticipated to almost double to 23% (UN, 2017). China is no exception. According to the World Population Aging Report (UN, 2017), the proportion of Chinese inhabitants aged over 60 is projected to rise from 16% (0.23 billion) in 2017 to 35% (0.48 billion) by 2050. By then, nearly one-fourth of older population in the world will live in China. This is largely the result of increased lifespans, declined fertility (especially in China following the 'one-child policy'), and the baby boomer aging. Importantly, elderly people are at higher risks of isolation and social exclusion due to physical constraints, widowhood, or the death of intimate friends or family members. Our rapidly aging society has therefore prompted the need for interventions that improve elderly's quality of life. In the context of China, walking has the largest modal share in seniors' daily travel patterns.[1] Walking as a means of transportation is thought to be of significant relevance to maintain social participation for Chinese elderly people (Cheng et al., 2019a; Feng, 2017). As a consequence, it is of great interest to better understand walking accessibility of older adults in order to propose tailor-made interventions. Investigating spatial variations in walking accessibility among older adults facilitates the identification of areas with substandard accessibility levels and with potential risks for transport-related social exclusion.

An important dimension of tackling social exclusion concerns involvement in activities which provide social interaction with others in the community. The role of the built environment (such as transportation, community facilities and services) is well acknowledged to be essential in providing access to various activities (Cheng et al., 2017, 2019c; Ewing and Cervero, 2010; Feng, 2017; Handy et al., 2005). Therefore, the fields of planning, design, policy, and practice should all align with appropriate guidelines that enhance social inclusion for older adults. Following Schwanen et al. (2001) and Cheng et al. (2019a, 2019b), recreational amenities (such as parks, chess/card rooms, cinemas, or public libraries) provide benefits of social integration and some of the most important opportunities for social involvement of the elderly as few of them still work. Recreational activities also have an encouraging influence on active lifestyles (De Vries et al., 2003) and may thus be beneficial to individuals' health: better cognitive performance, higher self-perceived health, lower likelihood of depression, and fewer disabilities (Julien et al., 2015).

In order to benefit from the activities conducted at recreational destinations, older individuals must have a reasonable level of accessibility to these places.[2] High accessibility to

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[1] In China, walking is the primary travel mode for older adults, especially in large cities. For instance, walking accounts for 68%, 52% and 61% of seniors' daily trips in Beijing, Shanghai, and Nanjing, respectively (Cheng et al., 2019a; Huang and Wu, 2015).

[2] This study draws on the concept of physical accessibility in that recreational amenities (e.g. chess/card rooms, urban parks) discussed in our analysis have to be reached in the physical space by older people. Virtual accessibility, also known as the ICT-based accessibility (Kenyon, 2010; Van Wee, 2016), defined as the Internet-

recreational amenities is conducive to fostering social involvement among elderly people, which is strongly relevant to their quality of life or well-being (Banister and Bowling, 2004; De Vos, 2019). For instance, as demonstrated by Chiesura (2004) and van den Berg et al. (2010), increased accessibility to public parks improves the likelihood of elderly's visiting, and in turn contributes to increased physical activity and human-nature interactions. In addition, inequalities in the distribution of recreational facilities have adverse effects on the elderly who already often face a lower social and economic status. This could further deteriorate the disparity in health and well-being outcomes across age cohorts. Talen (1998), for example, supports for making a linkage between accessibility and equity when providing urban amenities in order to improve the likelihood of social inclusion. The topic has witnessed an increasing interest, with many studies employing accessibility as an indicator to evaluate social equity (Delbosc and Currie, 2010a; Fan et al., 2012; Hickman et al., 2017; Ricciardi et al., 2015). Equity in accessibility basically describes the issue of who is favored and who is deprived from policies on land use and spatial planning, and how these benefits and burdens are distributed across society (Di Ciommo and Shiftan, 2017; Kaplan et al., 2014; van Wee and Geurs, 2011). The general principle is that infrastructure and service investments ought to not only enhance the average accessibility across overall urban areas, but also, and perhaps above all, benefit the vulnerable and dependent population.

Over the last decade, a few studies have examined accessibility of the elderly to recreational amenities, in particular green spaces, plazas, or urban parks (Julien et al., 2015; Parra et al., 2010; Rojas et al., 2016; Schwanen et al., 2001). However, to the best of our knowledge, we are not aware of such research in the Chinese context with an explicit focus on equity. Deeply influenced by Confucianism, Taoism, and Buddhism, Chinese socio-cultural norms make recreational activities of the elderly of specific importance. In general, Chinese elderly tend to regularly engage in a range of 'passive' recreational activities, for instance, playing chess and cards, *mahjong*, and talking with neighbors or friends (Ito et al., 2014; Liu et al., 2008). Accordingly, chess/card rooms and urban parks are places of great importance for Chinese elderly to perform some of these recreational activities. Using activity-travel survey data, Cheng et al. (2019a) and Feng (2017) empirically confirmed the significant effects of chess/card rooms and urban parks on the mobility of the elderly in China. Against this backdrop, the objective of this research is to examine the accessibility to recreational amenities of older adults in the Chinese context. More specifically, we examine the equity of walking accessibility to chess/card rooms and urban parks.

This research contributes to the existing literature in three main ways. First, by incorporating a spatial expansion model, results evidence the soundness of an adaptive threshold for accessibility measurement, more accurately capturing elderly's activity spheres. Second, the use of vertical equity for assessing the distribution of walking accessibility proves powerful in identifying differences in access to recreational amenities, which may be useful for communicating findings to planners and policy-makers. Third, the differentiation of walking

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based accessibility which offers opportunities to reach goods or services without physical travel, falls beyond the scope of this research.

accessibility across geographical areas can provide insights in relation to the identification of priorities for interventions, aiming for the redistribution and enhancement of current levels of elderly's accessibility to recreational amenities.

The remainder of this paper is organized as follows. Section 2 makes a literature review on accessibility and equity, followed by Section 3 in which our Nanjing (China) case study and the data collection are introduced. Section 4 focuses on the research methodology, while Section 5 elaborates on the findings. Finally, major conclusions and future research avenues are given in Section 6.

2 Literature review

2.1 Accessibility measurement

The concept of accessibility has long been adopted in both spatial and transportation research to assess the quality and extent of the relationships between spatial development of a certain area and the transportation system serving it. The seminal work of Hansen (1959, p.73) defined accessibility as "the potential of opportunities for interaction", measuring the number and variety of opportunities which can be obtained from a specific location by means of the transportation system. While a plethora of definitions have since been proposed to refine the concept (Cascetta et al., 2016; Dong et al., 2006; Geurs and van Wee, 2004; Handy and Niemeier, 1997), most of them include activities or destinations, and travel impedance (e.g. time, cost, and effort): the more alternatives for reaching destinations or conducting activities and the lower the travel impedance, the higher the level of the accessibility. Geurs and van Wee (2004) deconstructed the concept of accessibility into four elements: i) land use, which describes the quality, quantity, and spatial distribution of opportunities, such as schools, jobs, hospitals, and recreational facilities as destination places, as well as demand for opportunities at origin places; ii) transportation, which refers to the transportation system represented by the disutility for a person to travel from an origin to a destination by means of a certain mode of transportation; iii) time, which accounts for the temporal constraints in terms of the availability of opportunities throughout the day and the available time for people to utilize such kind of opportunities; and iv) individual, which indicates the capabilities (determined by income, education level, travel mode availability, etc.) and needs (determined by age, household situation, etc.) of specific (groups of) persons.

The emphasis on different elements of accessibility has resulted in multiple measurement methods and indicators (for example, Geurs and van Wee, 2004; Kelobonye et al., 2019; Lee et al., 2010; Neutens, 2015; Paez et al., 2012; and Vandenbulcke et al., 2009), including proximity, cumulative, gravity, utility-based, and space-time prism models as the dominant approaches. Proximity models provide spatial information on the closeness between locations with respect to travel distance, time or generalized cost. Cumulative models, also known as isochrone models, evaluate the accessibility as the cumulative number of potential opportunities available within a specific threshold of time or distance (Morris et al., 1979). Proximity models and cumulative models require relatively little data and results are easy to explain (Deboosere and El-Geneidy, 2018). Gravity models are a zonal approach which measures the potential of opportunities for interactions, quantified as the amount of activities between zones, by impedance functions representing generalized travel cost (Batty, 1976). The fourth set of accessibility measures revolves around the utility-based model, which grounded in random utility maximization (RUM) theory. This approach explicitly considers behavioral characteristics of decision-makers, assuming that an individual choosing the alternative with the highest utility relative to all other potential choices (Ben-Akiva and Lerman, 1985; Hess and Daly, 2014). In the space-time prism model, it is recognized that people's activities have spatial and temporal dimensions: activities take place at particular locations for limited durations. Space-time accessibility is strongly contingent on space-time constraints (Miller, 1999) regarding capability (physical limit, e.g. how fast an individual can walk), coupling (commitment, e.g. work times), and authority (regulations for curbing movement, e.g. driving restrictions). Compared to proximity and cumulative models, gravity, utility-based and space-time prism models have more requirements on data (e.g. amount, quality, explanatory power) for model calibration (Kelobonye et al., 2019; Vandenbulcke et al., 2009).

Cumulative opportunity approaches have been extensively adopted for measuring accessibility because of their relative ease in operationalization, interpretation, and communication, all of which increase the likelihood of being used by practitioners (Caset et al., 2018; Fan et al., 2012; Guy, 1983; Kelobonye et al., 2019; Kim and Sultana, 2015). This approach nonetheless faces drawbacks concerning the degree of subjectivity in selecting the spatial/temporal threshold for the calculation of the available opportunities (Bertolini et al., 2005; Handy and Niemeier, 1997). The level of accessibility is, to a large extent, contingent on a certain threshold, for example, the number of shops within 1km may be quite different from those within 2km. Paez et al. (2010a) developed empirically-based estimates of distance traveled, giving much flexibility to analyze accessibility that is specific to an individual and a location in space. Instead of using a fixed threshold, their calibrated cumulative model uses an adaptive threshold for measuring opportunities. The use of adaptive thresholds implies that accessibility could vary for different individuals even at the same location, as well as account for the variability in travel impedance even for identical individuals at different locations. In this study, we employ the approach put forward by Paez et al. (2010a), generating statistically valid thresholds of walking distance which improve behavioral realism when compared to arbitrarily fixed thresholds. The adaptive threshold is estimated by the spatial expansion model.

2.2 Accessibility equity

Accessibility is often utilized to differentiate the effects of land use and transportation planning across socio-economic groups or geographical areas (Lucas et al., 2016; Martens, 2016), with an increasing body of literature engaging with the connection between accessibility and equity (see, among others, Cui et al., 2019; Delbosc and Currie, 2010a, 2010b; Guzman et al., 2017; Lee and Miller, 2019; Ricciardi et al., 2015). Accessibility-related social inequities exist across the entire range of urban services, including access to jobs, schools, housing, transportation, and healthcare facilities (Hu et al., 2017; Zhao and Howden-Chapman, 2010). The analysis of accessibility equity relates not only to the provision of equitable transportation for all inhabitants in a city, but also land use developments and regulations concerning the ability of different (groups of) people to make use of opportunities (van Wee and Handy, 2016). Two major concepts could be discerned in previous studies on the understanding of equity in transportation: horizontal equity and vertical equity (Fan et al., 2019; Fransen et al., 2015; Guzman et al., 2017; Litman, 1999; Manaugh et al., 2015). The former implies the equal distribution of costs and benefits between people with equal abilities and equal needs. As noted by Delbosc and Currie (2011b), this concept is more relevant to the principle of "mass transit", which aims to transport the maximum number of travelers. The latter, on the other hand, indicates that disadvantaged individuals should be identified so as to design specific policies satisfying their needs. Vertical equity, therefore, opens up the potential for a more "socially-focused" approach where specific groups of vulnerable or disadvantaged persons are targeted by policies. In this aspect, if disadvantaged individuals – such as elderly people – experience lower levels of access to urban amenities than non-disadvantaged individuals – such as younger adults – there is inequity.

Several earlier studies addressed the issue of equity in the assessment of land and transportation development policies (Ricciardi et al., 2015; Wu and Hine, 2013). Lucas et al. (2016) indicated that the widely adopted approach for policy evaluation, i.e. multi-criteria or cost-benefit analysis, does not properly address the equity impacts, or risks double counting policy benefits. Lorenz curves and Gini index have been used to evaluate accessibility and equity between different social groups and/or areas (Delbosc and Currie, 2011b; Karlström and Franklin, 2009; Lucas et al., 2016). Delbosc and Currie (2011b) used Lorenz curves to calculate the overall supply equity of public transit in Melbourne, while in the study of Karlström and Franklin (2009) the Gini index was used as an indicator of equity in an evaluation of the impacts of the congestion pricing scheme in Stockholm. Lucas et al. (2016) also evaluated socially-specific accessibility influences of urban amenities, applying Lorenz curves and Gini indices. In addition, Spearman's rank correlation coefficient, a scale-independent indicator, has been used to assess the vertical equity in accessibility (Adli and Donovan, 2018; Deboosere and El-Geneidy, 2018), and it has the advantage of being readily interpretable and easily explainable to policy-makers.

2.3 Accessibility for elderly people

Accessibility problems can put restrictions on older adults from maintaining active and participating in social activities (Hallgrimsdottir et al., 2015; Hess, 2009). Research has shown that walking barriers such as narrow pavements, uneven surfaces, high curbs, poor crosswalks make older people stop walking (Stahl and Berntman, 2007), while limited access to public transit – in particular walking access to stations/stops – is a significant constraining factor on transit ridership of older adults (Hess, 2009; Lin et al., 2014). Chiesura (2004) and van den Berg et al. (2010) found that inadequate access to urban parks leads to decreased intensity of elderly's physical activity and human-nature interactions. In addition, spatial barriers for older people to reach healthcare services contribute to lower utilization of healthcare facilities and decreased uptake of disease-preventing services, which may in turn cause poorer health outcomes (Neutens, 2015; Zhang et al., 2018). Using face-to-face interview survey data collected in Vancouver, Cvitkovich and Wister (2001) observed that elderly people who lack access to transportation are prone to experience declined wellbeing compared to their peers with better access to transportation alternatives.

Accessibility is one of the key elements which are conducive to community integration of elderly population, with individuals having increased access to opportunities reporting lower levels of social isolation and higher levels of quality of life (Banister and Bowling, 2004; Sze and Christensen, 2017). Accessibility needs of the aging population differ from those of other age cohorts (Horner et al., 2015). Cao et al. (2010) further noted that accessibility plays a more important role in influencing travel behavior of elderly people than that of younger adults. Therefore, a targeted emphasis on accessibility interventions will mainly benefit seniors, which may enable the elderly to feel a sense of independence, security, and dignity (Alsnih and Hensher, 2003). To support aging-in-place, both land use and transportation policies are important. For example, tax exemptions and zoning changes could attract local stores and services to elderly-concentrated neighborhoods (Cao et al., 2010); flexible public transit services including demand-responsive transit and shared-ride shuttles in suburban areas will allow older residents to access distant destinations (Alsnih and Hensher, 2003); pedestrian-friendly neighborhood design increases the intensity of walking and protects older people from immobility (Wennberg et al., 2010).

An uneven distribution of urban facilities and transportation supply can create adverse effects for the elderly who often already face disadvantages for social and economic reasons. This might further deteriorate the disparity in well-being outcomes between older and younger groups. Achuthan et al. (2010) investigated the disparities in walking travel for elderly people, demonstrating that walking barriers could greatly hinder the elderly's mobility. Ricciardi et al. (2015) also showed that older people experienced the most inequitable distribution of public transit services relative to other socially-disadvantaged groups (i.e. non-car-owner households and low-income households). Some studies have examined the accessibility and equity of urban healthcare services for older adults (e.g. Acharya et al., 2019; van Gaans and Dent, 2018; Zhang et al., 2018). The injustices of access and utilization of health care services are strongly linked to inequitable health outcomes. Developing affordable and good-quality healthcare services for the elderly population to ensure the equity in access will be a crucial task in an aging society (Acharya et al., 2019).

3 Data

Our study was conducted in Nanjing, a mega-city with a population of 8.2 million (in 2015) located in eastern China (Figure 1). Nanjing is a monocentric metropolitan area and consists of eleven administrative districts, including nine districts in the main city area. With respect to the demographic composition, 21% of the population in Nanjing was aged 60 and older (in 2015). According to official projections, the proportion of older adults in Nanjing will grow to 30% in 2030 (China National Working Commission on Aging, 2016). The main city area of Nanjing is partitioned into 495 traffic analysis zones (TAZs, mean size and standard deviation are respectively 1.77 km^2 and 2.37), which are the basic territorial units for planning the transportation system and defining urban functions at the local level. Analysis of accessibility in Nanjing is conducted at this TAZ level. In this research, we operationalize 'the elderly' as those aged 60 or above while individuals between 18 and 60 are considered as younger adults.

Two sources of data are used for our accessibility analysis. The first is the 2015 Nanjing Travel Survey conducted by the local government. The survey was carried out by means of household interview on a typical weekday (i.e. Wednesday October 28^{th} 2015), and reached almost 12,000 households and 35,600 individuals selected in a randomized way. It collected information on travel behavior (trip origin and destination, purpose, starting and ending times, and mode choice) of each person (aged six or older[3]) in the household interviewed. Moreover, the survey also recorded socio-economic characteristics about households and individuals. Place of residence, as well as trip starting and ending locations, was geocoded using the Baidu Map API services. There are 92,334 trip records for respondents who conducted out-of-home activities on the surveyed day. When compared to the Statistical Yearbook of Nanjing (Nanjing Municipal Bureau Statistics, 2016), the overall distribution of age, gender and household income groups corresponds to the census data, indicating that the survey data are representative. In Nanjing, the predominant travel purpose of older adults is for recreational activities (46%). The most popular travel mode is walking (61%). Bicycle (10%), public transit (20%) and private car (4%) have a much lower modal share.

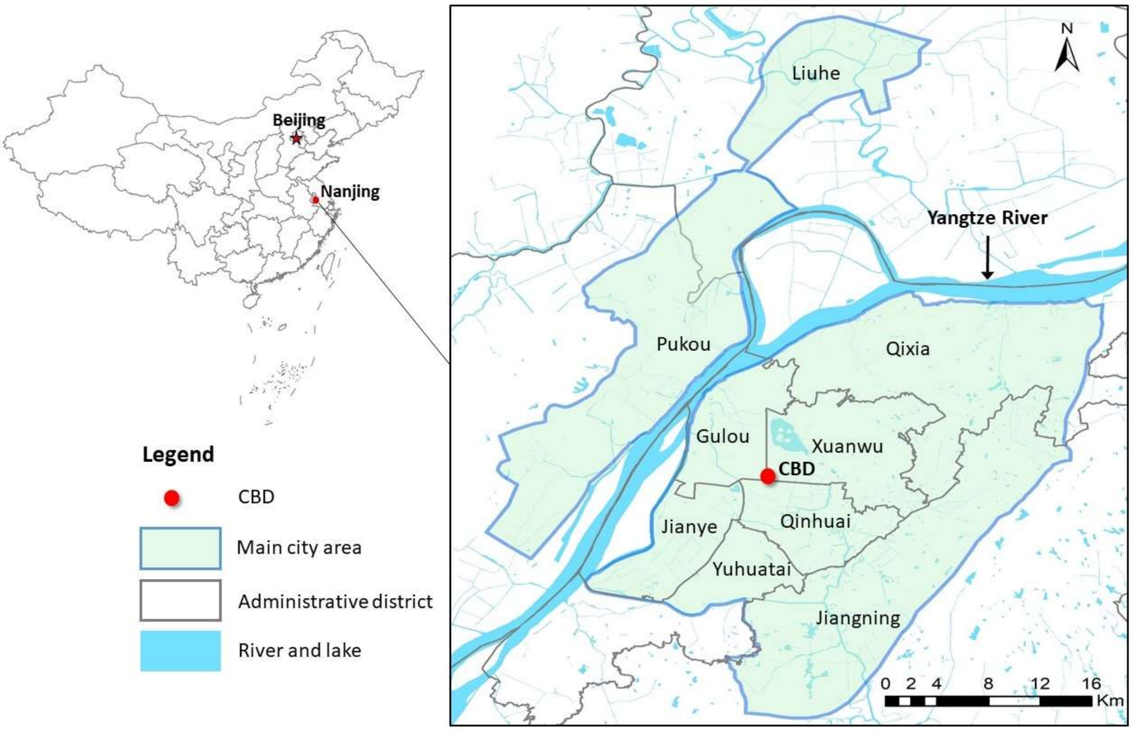

Figure 1 Study area in Nanjing, China

The second source of information is the Nanjing city GIS database. It includes a variety of points of interests, e.g. educational and medical facilities, transportation infrastructure,

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3 Respondents between 6 and 17 are removed from the sample given that we focus on the adult population (i.e. elderly and younger adults) in this research.

commercial and business services, and government organizations. Our selected points (i.e. parks and chess/card rooms) are closely related to recreational destinations preferred by the elderly. As a result, there are 387 parks with a total area of 840km^2, and 1,145 chess/card rooms in the main city (Figure 2). The largest two urban parks are the Laoshan National Forest Park and the Zhongshan Scenic Area, with a surface area of 20km^2 and 11km^2 respectively.

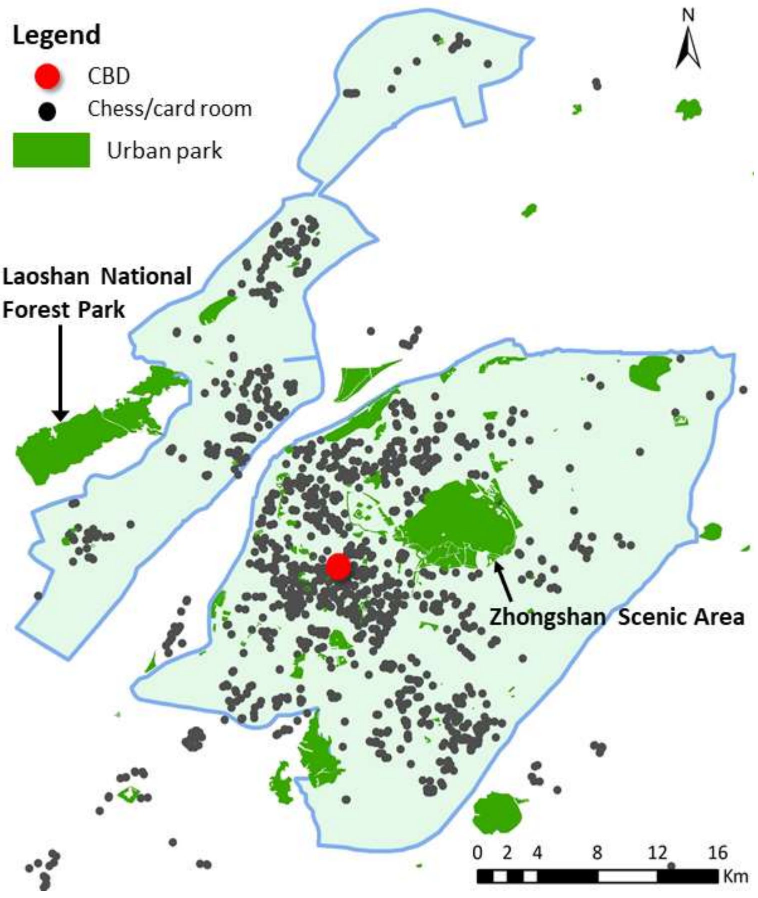

Figure 2 Distribution of chess/card rooms and urban parks

From the Nanjing Travel survey, personal information of respondents can be extracted to generate covariates for modeling (Table 1). Individual socio-economic variables are age, gender, transit card ownership, driving license ownership, and education level. Household-level variables include household size (the number of family members), annual household income (in RMB, 1RMB=0.16USD in 2015), presence of children under six years old, car ownership, and bicycle ownership. In addition, we also consider built environment variables as they can affect travel behavior. These variables include land use mix, population density (persons/km^2), and road density (km/km^2), and are measured at the level of TAZ based on the city's GIS database. Land use mix is represented by an entropy indicator as $-\sum_i (P_i \ln(P_i))/\ln(I)$ where P_i is the percentage of the ith land use type $(i = 1,2,\ldots,I)$. There are five types of land use in our analysis: residential, education, public services, commerce and business, and entertainment.

Table 1 Descriptive statistics of elderly respondents

Variable	Description	Frequency	Percent
Individual level		# of individuals = 7,460	
Gender	Female	4013	53.8%
Transit card ownership	Yes	6453	86.5%
Driving license ownership	Yes	686	9.2%
Education level	Low	3887	52.1%
	Middle	2678	35.9%
	High	895	12.0%
Household level		# of households = 2,390	
Household size	Number of family members	/	Mean = 3.12
Household income	< 50,000 RMB/year	949	39.7%
	50,000-100,000 RMB/year	798	33.4%
	> 100,000 RMB/year	643	26.9%
Child presence	Yes	557	23.3%
Car ownership	Yes	939	39.3%
Bicycle ownership	Yes	1663	69.6%
Built environment		Mean	SD
Land use mixture		0.62	0.14
Population density (persons/km^2)		3210	1122
Road density (km/km^2)		7.15	2.96

Note: "/" means not applicable; SD is the standard deviation.

4 Methodology

4.1 Spatial expansion model

Accessibility measurements commonly use a fixed threshold, e.g. travel time or a distance threshold. These measurements exclusively depend on the spatial distribution of facilities but ignore the personal and locational features. However, from a geographical perspective, individuals perceive and use space in a different way depending on their profiles and locations. For example, walking for 30min could be a quite distinct and more onerous experience for an 80-year-old person compared to a 30-year-old person. This experience for a person who is 80 years old could also be different in the city center than in suburbs. Therefore, we opted to use adaptive thresholds – empirically-based estimates of average travel distances – to measure accessibility. Average travel distance is an all-purpose indicator of a person's actual reach and mobility, and serves as a practical proxy for daily activity space (Morency et al., 2011; Schönfelder and Axhausen, 2003). This measure is a more practical benchmark for calculating accessibility in the way that it catches hold of potential opportunities within the travel distance of a typical trip.

A multivariate regression model is useful to estimate the average travel distance. To account for the geographical variations of individuals' mobility, the expansion method is applied to derive models with spatially varying coefficients (Casetti, 1972, p.85). A spatial expansion model expands the coefficients of a preliminary model using functions of the coordinates of the samples (Fotheringham et al., 1998; Fotheringham and Brunsdon, 1999). As a straightforward illustration, we show a preliminary model with a constant term β_0, an independent variable and its coefficient (X_i,β_i), and an error term ε_i:

$$Y_i = \beta_0 + \beta_i X_i + \varepsilon_i \tag{1}$$

Suppose that β_i can be expressed as a function of the coordinates u_i and v_i (i.e. longitude and latitude), shown as:

$$\beta_i = f(u_i, v_i) \tag{2}$$

Equation (2) could be represented as a quadratic form of the coordinates (other forms of polynomial expansion are also applicable), with parameters θ:

$$\beta_i = \theta_1 + \theta_2 u_i + \theta_3 v_i + \theta_4 u_i^2 + \theta_5 v_i^2 + \theta_6 u_i v_i \tag{3}$$

The final model is then acquired if we replace Equation (3) into Equation (1):

$$Y_i = \beta_0 + (\theta_1 + \theta_2 u_i + \theta_3 v_i + \theta_4 u_i^2 + \theta_5 v_i^2 + \theta_6 u_i v_i) X_i + \varepsilon_i \tag{4}$$

It should be noted that in order to avoid scale problems in the model estimation, all coordinates have been normalized to a one-unit rectangle. This is done by taking the maximum extent of coordinates and dividing the difference in each coordinate and the minimum coordinate value in the corresponding axis, represented in Equations (5) and (6) where u_i^n and v_i^n are the normalized coordinates.

$$u_i^n = \frac{u_i - \min(u)}{\max(\max(\boldsymbol{u}) - \min(\boldsymbol{u}), \max(\boldsymbol{v}) - \min(\boldsymbol{v}))} \tag{5}$$

$$v_i^n = \frac{v_i - \min(v)}{\max(\max(\boldsymbol{u}) - \min(\boldsymbol{u}), \max(\boldsymbol{v}) - \min(\boldsymbol{v}))} \tag{6}$$

In our analysis, the dependent variable is the logarithm of average walking distance ($Y_i = \log(d_i)$), where the average walking distance d_i is calculated as the total (pedestrian) network-based walking distance traveled for all purposes divided by the number of walking trips. Network-based walking distance is the length of the shortest path from trip origin to destination along the pedestrian network. The log-transformed of d_i is made to make sure that the model produces positive travel distance prediction, and compresses the distributional scale of this variable. The modeling process uses the full sample of people who performed walking trips (including respondents besides older people) and takes into account all trip purposes. Consequently, we have a relatively large sample size, which is beneficial to derive a robust indicator of mobility. With regard to expansions, the following variables are considered for the estimation of expanded coefficients: age, gender, income, and car ownership. These variables are selected based on theoretical considerations (e.g. car ownership may contextually vary across locations) and a review of similar studies (e.g. Paez et al., 2013; Reyes et al., 2014; Rojas et al., 2016; and Roorda et al., 2010).

Evidently, the chief merits of the expansion method lie in the ability to model contextual variations, which allows us to acquire person- and location-specific estimates of distance traveled. At each location in space, respondents are distinguished by their socio-economic attributes and can be compared explicitly regarding their mobility. The spatial expansion model can be estimated with the use of the conventional ordinary least squares approach. The estimated model is used to obtain adaptive thresholds of walking distance. These distance thresholds, in turn, are utilized to calculate the level of accessibility to recreational amenities, as discussed below.

4.2 Measuring accessibility

In this research, we apply the cumulative approach for measuring accessibility using the adaptive thresholds discussed above. The accessibility indicator is defined as follows:

$$A_{pi}^{m} = \sum_{j} W_{j}^{c} I(d_{ij} \leq d_{pi}) \quad (7)$$

$$A_{pi}^{n} = \sum_{d_{ij} \leq d_{pi}} W_{j}^{a} \quad (8)$$

where A_{pi}^{m}, A_{pi}^{n} are the accessibility to chess/card rooms and urban parks by person p from location i, respectively; W_{j}^{c} is the count of chess/card rooms at location j; W_{j}^{a} is the area of park j of which space is located within d_{pi}; $\mathrm{I}(\cdot)$ is an indicator function which takes the value of one if the distance of arriving at j from i is not larger the threshold d_{pi}, and 0 otherwise. The adaptive threshold d_{pi}, specific to person p and location i, is estimated using the spatial expansion model explained in the previous section. As such, the level of accessibility is a behaviorally-derived measure depending on empirical mobility pattern observed in the sample.

The number of facilities within the adaptive threshold is calculated as the accessibility to chess/card rooms. For the accessibility to urban parks, however, the area of park spaces at j is considered because the size of these parks varies widely. Figure 3 illustrates how accessibility to parks is measured. Assume two persons with identical profile p living at locations r and m. The person at r is estimated to walk a longer distance. Given the distribution of parks, this person living at r has a higher accessibility. The person living at m, despite being nearer to these two parks, has a lower access because of a lower walking mobility ($d_{pm} < d_{pr}$).

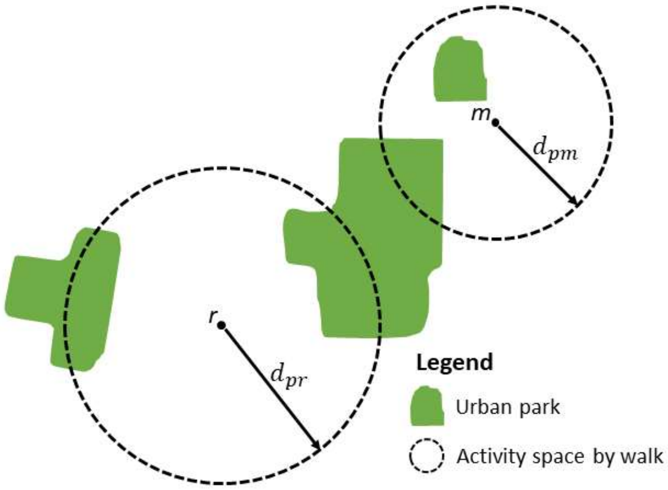

Figure 3 Example of measuring accessibility to urban parks

4.3 Vertical equity

In an age-friendly society, we argue that a community with a higher percentage of older population should have a higher level of accessibility to recreational amenities. To discern the level of accessibility by age cohorts, an aging index – the percentage of older people in the sample – is estimated at the TAZ level. A vertical equity indicator is then calculated on the basis of the aging index to identify whether walking accessibility to chess/card rooms and parks is equitably distributed. It is noted that in Chinese cities, each administrative district (e.g. the nine districts in Nanjing main city area, as presented in Figure 1) has access to a substantial amount of municipal and financial resources as it is basically the main body implementing land use and transportation development interventions. In order to offer a practical guide for policy-makers, this study calculates the vertical equity indicator for each administrative district. A Spearman's rank correlation coefficient between the aging index and the level of accessibility is calculated for each district. It evaluates whether TAZs with the highest aging index also have the maximum level of accessibility:

$$VE^d = \rho_{rAcc\_t,\quad rAge\_t} = \frac{cov(rAcc\_t, rAge\_t)}{\sigma_{rAcc\_t}\sigma_{rAge\_t}} \tag{9}$$

where VE^d denotes the vertical equity indicator for administrative district; $\rho_{rAcc\_t,rAge\_t}$ is Spearman's rank correlation coefficient corresponding to the rank of walking accessibility and the rank of the aging index for each TAZ; $cov(rAcc\_t, rAge\_t)$ refers to the covariance matrix of the ranked variables (i.e. level of accessibility and aging index for each TAZ); and σ_{rAcc_t}, σ_{rAge_t} are the standard deviations.

5 Results

5.1 Estimated walking distance

The estimation results of the spatial expansion model are shown in Table 2. These calculations exclude the return-home trip, resulting in 22,610 walking trips. The overall goodness-of-fit, R^2 and R^2_{adj}, are 0.250 and 0.219, which is comparable to similar models reported in the literature (Morency et al., 2011; Paez et al., 2010b, 2012). Since variable interactions are incorporated in the spatial expansion model, there might be a possible issue which merits discussion regarding multicollinearity. The effect of multicollinearity relates to the inflation of variance, which becomes evident when there are counterintuitive parameter signs, implausible parameter magnitudes, or significance loss in estimates of parameters (Casetti, 1997). Although these problems are potentially serious, O'Brien (2007) shows that sample size could deflate the variance substantially greater than the extent of inflation caused by multicollinearity. In this study, the large sample size (number of walking trips = 22,610) and the absence of any problems resulting from multicollinearity (demonstrated in Table 2) are indicative of the good quality of model results.

Table 2 Results of spatial expansion models

Variable	Estimate	p-value	Variable	Estimate	p-value
Constant	13.757	0.008	*Spatial expansion*		
Socio-economic			u	-5.954	0.043
Age (60 or older =1)	-3.534	0.027	*Age	4.185	0.070
Gender (Male=1)	-6.115	0.031	*Gender	2.952	0.062
Transit card ownership (Yes=1)	0.315	0.185	*Income 50K-100K	-6.889	0.018
Driving license (Yes=1)	-1.056	0.028	*Income >100K	-8.434	0.010
Education level (Low=ref.)			*Car ownership	4.069	0.040
Middle	2.037	0.045	v	-9.906	0.005
High	1.028	0.028	*Age	9.245	0.044
Household size	-0.042	0.302	*Gender	2.829	0.045
Household income (<50K=ref.)			*Income 50K-100K	-8.808	0.007
50K-100K	4.478	0.006	*Income >100K	-7.017	0.003
>100K	3.498	0.003	*Car ownership	2.511	0.066
Child presence (Yes=1)	-1.769	0.086	u^2	-3.854	0.000
Car ownership (Yes=1)	-3.533	0.060	*Age	1.631	0.010
Bicycle ownership (Yes=1)	1.859	0.042	*Gender	0.932	0.098
			*Income 50K-100K	-2.504	0.005
Built environment			*Income >100K	-1.201	0.045
Land use mix	0.898	0.019	*Car ownership	0.278	0.056
Population density	0.632	0.015	v^2	9.084	0.003
Road density	0.006	0.392	*Age	-9.214	0.018
			*Gender	-6.454	0.061
Model fit			*Income 50K-100K	5.466	0.011
R square R^2	0.250		*Income >100K	9.186	0.005
Adjusted R square R^2_{adj}	0.219		*Car ownership	-9.786	0.021
Std error of the estimate σ	0.365		uv	2.691	0.050
# of observations N	22,610		*Age	-6.915	0.063
			*Gender	-4.273	0.082
			*Income 50K-100K	7.412	0.008
			*Income >100K	7.416	0.009
			*Car ownership	-4.622	0.068

In general, older people tend to walk shorter distances than their younger counterparts, suggesting a smaller range of potential opportunities that can be accessed by the elderly, all else being equal. Three other relevant observations can be made. First, large walking distances are associated with high household incomes, which is in line with the finding reported by Moniruzzaman et al. (2013). This is interesting because almost 40% of older people come from households with incomes below 50,000 RMB/year (Table 1). Second, high education levels are associated with positive effects on walking trip length. A relatively large proportion of older adults tend to be low-educated (52%), lowering their walking mobility. Last, car ownership and driving license ownership are negatively associated with average walking distance. Nevertheless, car ownership for elderly households (39%) is considerably lower compared to younger households (54%), encouraging – or forcing – elderly to walk longer. Driving license ownership exhibits a similar pattern – the proportion of older people owning driving license is much lower than that of younger people (9% versus 52%). As for the built environment variables, we can deduce that they are significantly related to walking behavior – high land use mix or population density increases the propensity to make long-distance walking trips.

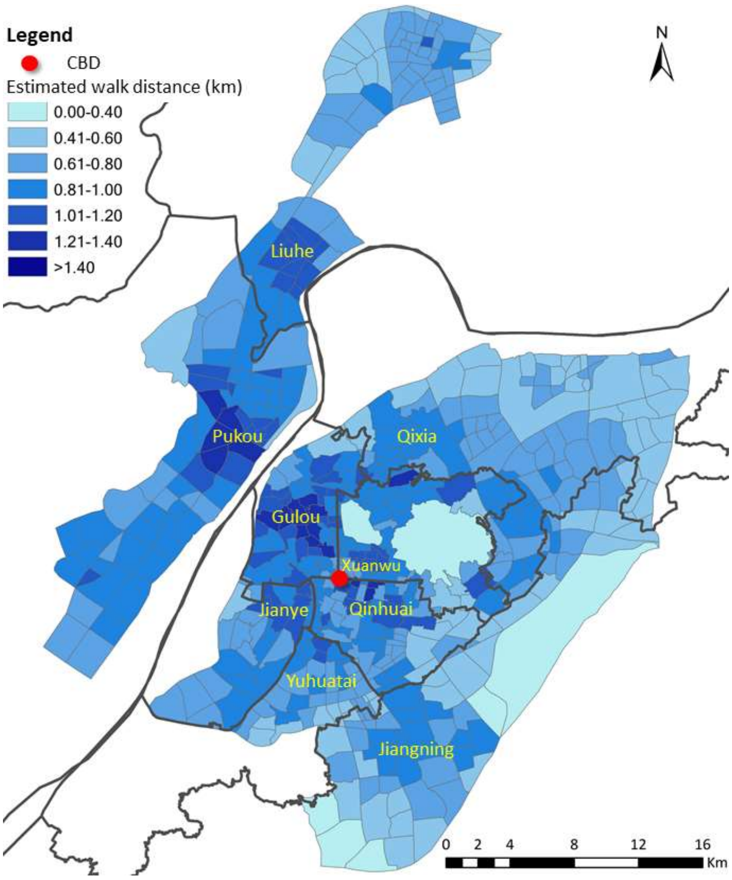

Figure 4 Estimated average walking distance of older adults

Results of the quadratic trend surface (i.e. spatial expansion using the coordinates) analysis are significant (Table 2), implying that estimated travel behavior varies across locations. The sign of coefficients displays general trends in walking mobility over space. For example, the signs of longitude and latitude (i.e. easting and northing) are both negative, indicating that the further to the west or to the south, the longer the overall walking distance. We calculated the zone-based average walking trip length. In each TAZ, the coordinates of the interviewed household locations are used to estimate the walking distance, in conjunction with the coefficients in Table 2 and the designated person file within the sample. Figure 4 shows the geographical pattern of the estimated average walking distance of older adults. We deduce that, in general, walking distances of older people in the downtown area are longer than those of people living in the periphery. It is clear that estimated walking distances of residents from different TAZs can vary a great deal, with a mean trip length of 764m and a standard deviation of 262m. With respect to the district level, older residents in Gulou walk the longest distances on average (978m/trip) while the elderly living in Liuhe have the shortest walking trip lengths (616m/trip). This considerable variation in average walking distance reflects distinct mobility pattern and activity spheres, influencing opportunity landscapes experienced by older adults from different areas. It also indicates the inappropriateness of a fixed threshold and evidences the soundness of an adaptive threshold for measuring accessibility.

5.2 Accessibility to recreational amenities

In this section, walking accessibility to recreational amenities using in-sample observations, pertaining to elderly and younger adults respectively, are calculated. For each person, the estimate of average walking distance is used as the adaptive threshold to measure the number of accessed opportunities. Then, accessibility for each TAZ is calculated by averaging the accessibility values of all individuals sampled from that TAZ. The averaged accessibility estimates at the TAZ level offer information regarding the level of access to chess/card rooms and urban parks, as displayed in Figures 5 and 6.

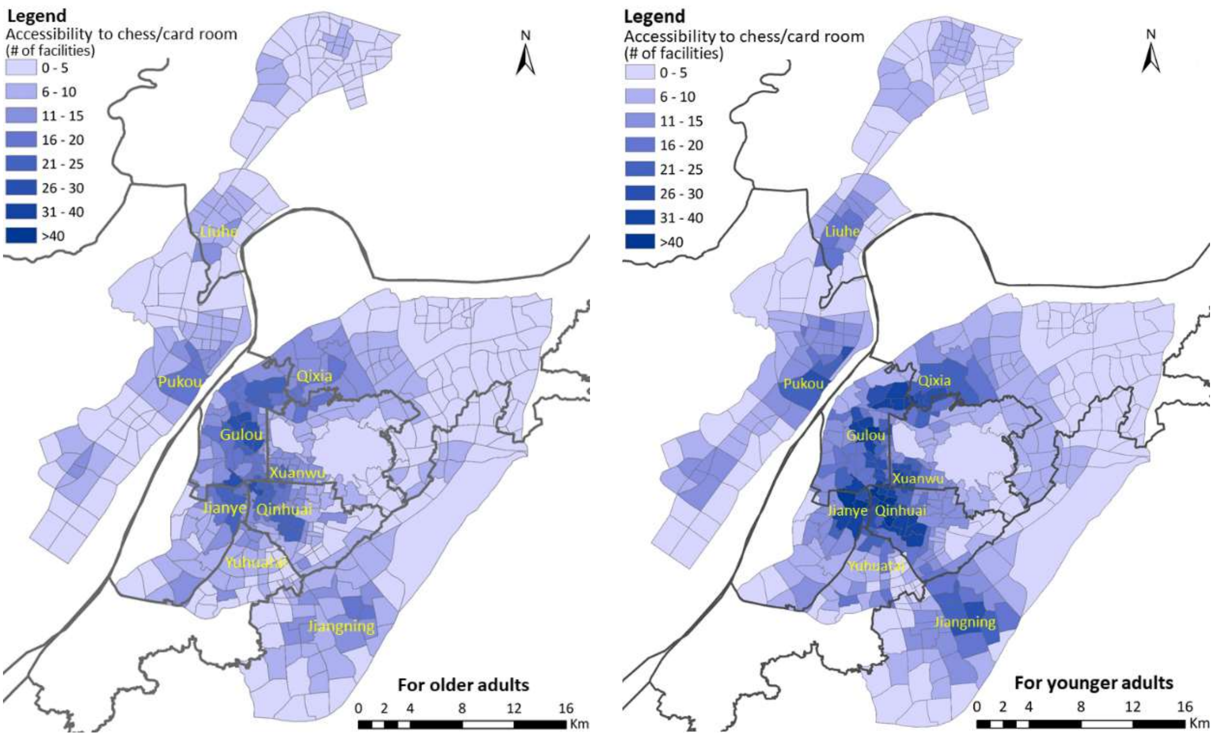

Figure 5 Estimated walking accessibility to chess/card rooms (left = older, right = younger)

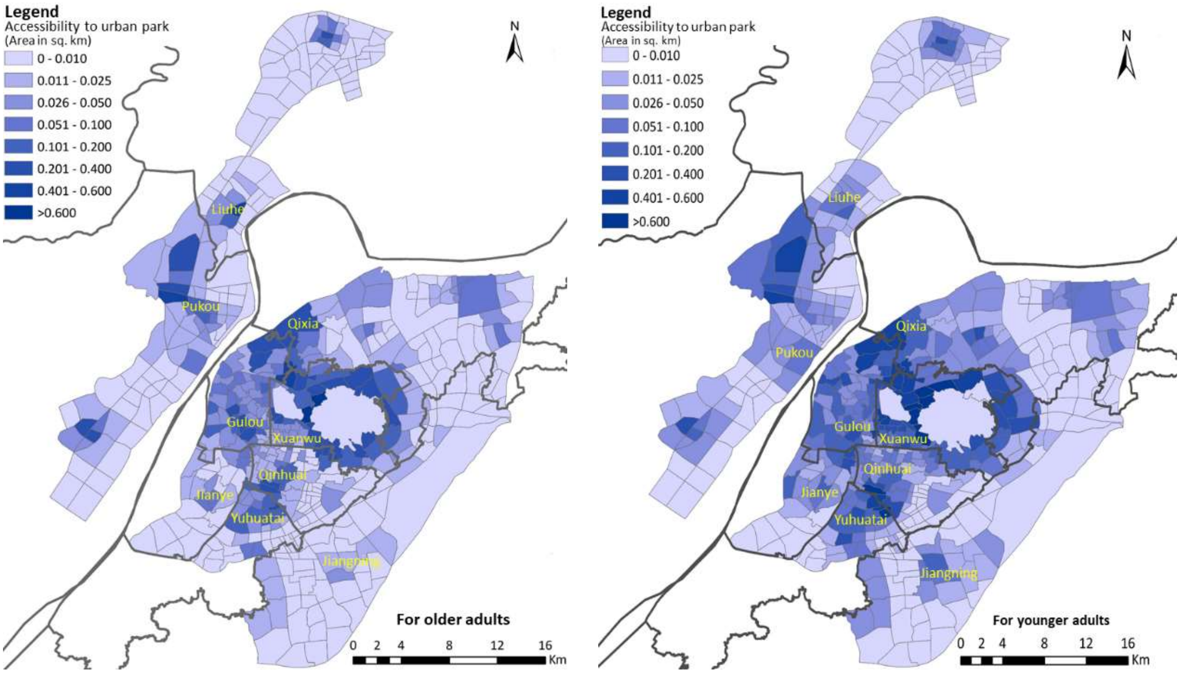

Figure 6 Estimated walking accessibility to urban parks (left = older, right = younger)

Figures 5 and 6 illustrate how the geographical pattern of recreational facilities is similar, with high levels of accessibility in the central part of the city where the Gulou or Xuanwu districts are situated, for both the elderly and the younger adults. High levels of accessibility to chess/card rooms are mostly identified in the area surrounding the CBD, where there is a concentration of chess/card rooms (Figure 2). The situation is not the same in the situation of accessibility to urban parks as the higher levels of accessibility are not very evident around the CBD. Urban parks remain more accessible in wider zones, containing a few highly accessible patches in the suburban areas. The general picture is indicative of different locational patterns in terms of chess/card rooms and urban parks, with more centralization in the former and centralized dispersion in the latter.

Drawing on these results, it becomes clear that older people experience lower accessibility compared to younger people. More specifically, on average, older people access four chess/card rooms within their typical walking activity space, while younger adults access seven such facilities. The decreased rate of accessibility to urban parks is 55.2%, from 0.045km^2 for the younger to 0.029km^2 for the elderly. In addition, the results indicate important spatial variations in accessibility for older people. For instance, residents in the Liuhe district tend to access much fewer opportunities for chess/card rooms with only two facilities on average. However, for the Gulou district, which has the largest number of such opportunities in the city, there are nine facilities. In the case of access to urban parks, Xuanwu district provides the most sufficient opportunities for the elderly (0.081km^2), contrasting Jiangning district with the lowest level of accessibility (0.004km^2). These disparities can be explained by two factors: discrepancies in the availability of recreational amenities and differentiated levels of walking mobility of individuals in those areas. This empirically informed evaluation of the current accessibility situation for older adults may indicate which areas are relatively disadvantaged and need interventions.

5.3 Equity in accessibility

The vertical equity in walking accessibility to chess/card rooms and urban parks, with a min-max normalization to a 0-1 range, is illustrated in Figure 7. The X-axis indicates the standardized average accessibility (i.e. level of accessibility) to recreational amenities where the highest level of accessibility across districts is one; and the Y-axis shows the vertical equity for each administrative district. A district point at (1,1) indicates the perfect circumstance: a district with a high level of overall access, and this access is more oriented towards elderly people (in other words, the TAZ with the highest aging index has the maximum level of accessibility). As for the chess/card rooms, Gulou appears to have both high accessibility and equity levels. In contrast, these two indicators show relatively low values in Yuhuatai, indicating that the elderly population has fewer opportunities than younger adults. In districts with fewer older adults (e.g. Jianye, Qixia, and Pukou) the equity in accessibility to chess/card rooms seems good, although the average level of accessibility is not high.

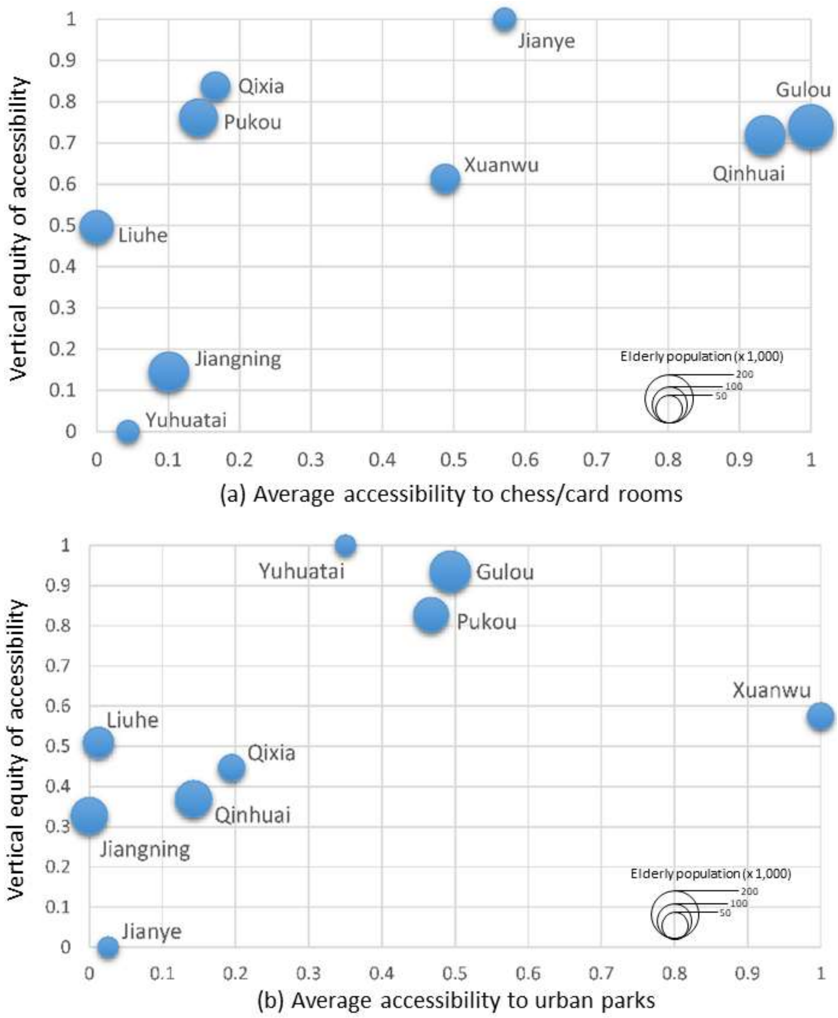

Figure 7 Accessibility and vertical equity across administrative districts (circle size indicates the size of the elderly population in each administrative district.)

Recreational amenities in two districts (Yuhuaitai and Jianye) appear to be most unevenly placed and distributed. More specifically, Yuhuatai has the highest vertical equity in accessibility to parks, although it has the lowest equity with regard to access to chess/card rooms. The same pattern holds for Jianye which has the lowest equity with regard to access to urban parks, but enjoys the highest equity with regard to access to chess/card rooms. Average level of accessibility to urban parks remains the highest in Xuanwu and the vertical equity in this district is also above average. When looking at recreational facilities overall, Gulou shows fairly satisfactory results: adequate accessibility as well as good vertical equity. This implies that older residents in Gulou have good accessibility to recreational amenities whilst enjoying greater access than their younger counterparts.

6 Conclusions

Taking into account the rapidly aging demographic landscape in China, securing elderly's right to participate in society has become an urgent challenge. The spatial distribution of opportunities has significant explanatory power in terms of the production of disparities in elderly's activity participation (Hallgrimsdottir et al., 2015; Julien et al., 2015). Therefore, older people should be a major focus in current accessibility policy packages. Results of this study concerning accessibility to recreational amenities in Nanjing may help to identify spatial and transport-related inequities for older adults.

In this study, we provided empirical evidence of differences in zone-based accessibility among the elderly, as a function of an individual's socio-economic and spatial context. Important variations in the level of accessibility and equity were shown. An adaptive threshold, i.e. average walking distance, was used to calculate walking accessibility to recreational amenities. Average walking distance is an all-purpose indicator of actual walking mobility and geographical reach and reflects individuals' daily activity spaces. Due to the fact that the provision of recreational facilities is geographically dispersed and walking mobility patterns of different individuals vary, the level of accessibility is also observed to be different across zones and age cohorts. In general, older adults have potential access to smaller number of recreational opportunities than younger adults, which may increase elderly's likelihood of social isolation/exclusion. It is noted that the lower accessibility to recreational opportunities experienced by older adults could be partly explained by their lowered ability (i.e. physical constraints) to walk greater distances. The older cohorts of the population, on the other hand, tend to have better access (to chess/card rooms, in particular) in central urban areas, but experience worse access in the peripheral parts of the city. Even though urban parks tend to be more frequently located in suburbs than chess/card rooms, this does not translate into much higher accessibility levels due to the relatively shorter walking trip length (i.e. smaller activity space) of suburbanites.

The marked disparities in accessibility between districts are helpful to identify the areas that are better-off or worse-off regarding recreational amenities. For instance, the elderly are better off in Gulou, with high accessibility levels and vertical equity. However, older residents in Liuhe and Jiangning experience relatively low levels of accessibility. Yuhuatai and Jianye witness the most unequal distribution in terms of chess/card rooms or urban parks. Spatial planning plays an important role in restraining transportation inequity (Zhao and Li, 2016). This unequal situation therefore might be tackled using a number of integrated land use and transportation strategies. First, pedestrian-oriented designs can be encouraged to meet the walking demand for older adults and provide sufficient opportunities for walking (in Liuhe and Jiangning districts, for instance). These may include land use mixing and residential densification (the significant effects shown in Table 2), e.g. diversify the composition and configuration of neighborhoods to make facilities in close proximity, and rezone land use which permits the integration of local recreational amenities to facilitate active lifestyles. Second, additional chess/card rooms and urban parks can be provided at senior-concentrated neighborhoods to allow older residents to live closer to these recreational facilities. Some existing (informal) open spaces could also be transformed into formal urban parks (in Jianye district, particularly).

The adaptive thresholds used for accessibility measurement are empirically derived from revealed walking behavior. Note that in some suburban TAZs, older people also walk for a longer distance, leading to a high threshold for the accessibility calculation. A possible question that can be raised, therefore, is: do people in these TAZs have the willingness to walk farther, or do they walk farther due to their limited choices? In fact, how far people walk is inherently dependent on their perceptions of the walking environment. Handy and Niemeier (1997) noted that in order to better plan for transport accessibility, the evaluation of accessibility should consider how people perceive their surroundings and reflect the elements which are important to them. The spatial expansion model nonetheless solely relies on walking distance – an objective indicator – to provide physical measure of access and hence is limited in capturing perceptions of accessibility. Perceived accessibility captures the individual dimension – the capabilities and needs of individuals (Geurs and van Wee, 2004) – and is more indicative of the evaluation of a socially inclusive transport system. It reflects an individual’s perceived ability to reach opportunities or services and is important to the identification of social exclusion (Lättman et al., 2018), constituting a better base for following up policy interventions for improved quality of life of older adults. Futures studies could develop a comprehensive approach – capturing both physical and perceived aspects – for the evaluation of accessibility. It is also interesting to investigate to what degree the threshold and derived level of accessibility are influenced by willingness or by constraint. If willingness is a more pertinent factor, it would be better to provide more recreational amenities near seniors’ homes or build affordable housing near existing recreational facilities. If, however, constraint mainly determines the level of accessibility, then practitioners should focus on removing these barriers with the provision of more walk-friendly infrastructure to increase individuals’ activity spheres.

The present research only investigates accessibility and does not consider the actual activity participation (i.e. the usage of facilities). To improve our understanding of older adults’ activity participation and social involvement, future work could therefore focus on relating accessibility to the actual usage of recreational amenities. In addition, the analysis of more specific built environment variables, e.g. four-way intersections and the presence of wide and well-lit sidewalks, may be needed to assist informed policy decisions about the planning and design of pedestrian-friendly neighborhoods. The methodologies used in this study have some limitations. First, the spatial expansion model incorporates geographical coordinates of household locations to allow for location-specific estimates of walking distance. The use of these variables, however, might cause overfitting and also has limited behavioral interpretability. Second, elderly people, for instance, may prefer to have a longer walk to urban parks in order to get some exercise but may favor shorter distances to access chess/card rooms. Future studies employing differentiated distance thresholds for different types of facilities would reveal accessibility landscape with more behavioral interpretation. Third, the cumulative model does not distinguish the attractiveness of facilities. Therefore, a hybrid model combining a cumulative approach with a gravity approach would likely produce more comprehensive accessibility outcomes. This study nonetheless provides valuable empirical insights for practitioners on elderly's walking accessibility to urban amenities, and allows deriving guidelines and targeted interventions for enhancing their access to various opportunities and services, in a way that is responsive to the rapid aging of the Chinese population.

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