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Greenspace exposure may increase life expectancy of elderly adults, especially for those with low socioeconomic status

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ABSTRACT

With an increasing aging population in many cities worldwide, promoting and maintaining the health of elderly individuals has become a pressing public health issue. Although greenspaces may deliver many health outcomes for the elderly population, existing evidence remains inconsistent, partly due to discrepancies in the measure of greenspace and health outcomes. In addition, few studies examined the effect of greenspace exposure on life expectancy at the individual level. Thus, this study comprehensively investigated the association between greenspace exposure and life expectancy among elderly adults in Guangzhou, China, based on the individual-level mortality dataset. The data were analyzed at both the individual level and aggregate level, and two types of buffers (straight-line vs. street-network buffer) were used to define individual greenspace exposure. After controlling for the random effects and multiple types of covariates, we found that 1) elderly individuals with higher greenspace exposure were associated with an increased life expectancy; 2) elderly individuals with lower socioeconomic status benefit more from greenspace (i.e., equigenesis hypothesis); 3) different greenspace measurements lead to different results; 4) greenspace had the highest effects on life expectancy and equigenesis within the street-network buffer distances of 3000 m and 2500 m, respectively. This study underscores the potential health benefits of greenspace exposure on elderly individuals and the importance of provision and upkeep of greenspace, especially among socially disadvantaged groups.

1. Introduction

Aging is a worldwide phenomenon that impacts both developed and developing countries; China is experiencing rapid and unprecedented aging, with its population aged 60 and over projected to reach 28% by 2040 (World Health Organization [WHO], 2023). Maintaining the health of elderly individuals has become a pressing public health issue, as they face a high burden of non-communicable diseases, disabilities, and inequalities (Liu et al., 2023; Wang and Chen, 2014).

Accumulating findings worldwide demonstrate that human interaction with nature, particularly greenspaces, generates significant physical and mental health benefits (Gascon et al., 2016; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018). Specifically, exposure to greenspaces is associated with long-term reduction of stress (Thompson Coon et al., 2011), accelerated recovery speed following surgical procedures (Ulrich, 1984), lower risk of type II diabetes (Astell-Burt et al., 2021), cardiovascular disease (Yao et al., 2022), respiratory problems (Orioli et al., 2019), and diminished risk of other chronic diseases (R. Mitchell and Popham, 2008). As individuals age, the incidence of the aforementioned diseases is higher among the elderly population (Ali et al., 2022; De Keijzer et al., 2020). Research has observed that the health benefits arising from exposure to greenspaces are more pronounced in elderly individuals (Astell-Burt et al., 2014; De Vries et al., 2003). Besides, greenspace facilitates interpersonal connections and fosters a feeling of belonging within a community (Ali et al., 2022). This aspect holds immense significance for the well-being of elderly individuals, who face heightened vulnerability to social detachment (Steptoe et al., 2013). The evidence underscores the crucial role of

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promoting access to greenspaces as a key strategy for improving public health, especially among the aging population.

Furthermore, the potential of greenspaces to mitigate health inequalities, articulated as equigenesis hypothesis, has recently gained research attention (Frumkin et al., 2017; R. J. Mitchell et al., 2015; R. Mitchell and Popham, 2008). The hypothesis postulated that the groups with low socioeconomic status (SES), who typically have less access to alternative resources promoting health, may benefit more from greenspaces, particularly those that are freely accessible (Mitchell and Popham, 2008; Moran et al., 2021).

Due to their straightforward, objective, and comprehensible nature, all-cause mortality has been widely utilized as indicators to assess the overall health and well-being of a population (Cheng et al., 2021; Connolly et al., 2023; Moran et al., 2021). However, existing research has shown inconsistent results in assessing the impact of greenspace. Several researchers suggested an association between higher exposure to greenspaces and decreased all-cause mortality (Markevych et al., 2017; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018). Nevertheless, a meta-analysis also reported an inconclusive link between greenspace exposure and all-cause mortality (Gascon et al., 2016).

Similarly, the existing evidence for the equigenesis hypothesis is also inconsistent. Some empirical studies support this hypothesis. For example, the effects of greenspace exposure were greater in groups with lower SES on all-cause mortality (R. Mitchell and Popham, 2008), mental health (McEachan et al., 2016; Mitchell et al., 2015; Wang et al., 2022), and violence-related mortality (Moran et al., 2021). However, there is also some evidence that does not support the equigenesis hypothesis, such as the evidence regarding general health (Feng and Astell-Burt, 2017), mental health (Sugiyama et al., 2016), and cardiovascular diseases mortality and life expectancy (Moran et al., 2021).

The variability in the evidence may be due to the variations in the methodologies employed to quantify greenspace across different studies. Although several nationwide research has investigated the health impact of greenspaces (Helbich et al., 2018; Kondo et al., 2020; Schinasi et al., 2019; Villeneuve et al., 2012; Wang and Tassinary, 2019) and the equigenesis hypothesis (Mitchell and Popham, 2008; Moran et al., 2021), most of them were conducted at the aggregate level (e.g., fishnet unit, zip code, census tract) rather than individual level. These aggregate-level studies are prone to ecological fallacy, the bias linking to the assumption that individuals share the same characteristics as their aggregate group, neglecting within-group and individual variations. Thus, such bias may result in a failure of hypotheses or conflicting results (Freedman, 1999; Piantadosi et al., 1988). In most circumstances, the frequency of ecological fallacy can be attributed to the absence of detailed individual-level data at a fine-scale level.

To avoid ecological fallacy, individual-level studies have been recently employed in health-greenspace studies. These studies typically used the straight-line buffer to assess the neighborhood greenspace exposure (Astell-Burt et al., 2021; Bauwelinck et al., 2021; Orioli et al., 2019); the straight-line buffer defines a circular area, which assumes that there are no obstacles and people can walk anywhere. However, in an urban environment, the activity space of an individual is limited by physical boundaries, such as fences, buildings, and rivers. Applying the street-network buffer, which assumes people can only access the area reachable within a street network, can result in more nuanced representations of an individual's surrounding environment (Droin et al., 2023; Ho et al., 2022, 2023). Although street-network buffers can provide a more accurate greenspace exposure, few studies have employed it to investigate the impact of exposure to greenspaces on health outcomes (e.g., mortality, life expectancy). In addition, although some scholars have pinpointed that different measurements of greenspace may be a primary factor in the inconsistency of the evidence (Feng and Astell-Burt, 2017; Wang et al., 2022), no empirical research has compared health outcomes with different measures of greenspace exposure (i.e., aggregate level vs. individual level and straight-line buffer and street-network buffer) using the same dataset at the citywide level.

In recent years, increasing health-related studies have focused on life expectancy loss, which is typically evaluated by years of life lost (YLL) (Cheng et al., 2021; Guo et al., 2013; Moran et al., 2021; Qi et al., 2020). Compared with mortality rates, YLL provides a more comprehensive and informative measure of the health impact, as it accounts for life expectancy loss at the time of death, adjusted for age and sex demographics (Cheng et al., 2021). Thus, YLL is not vulnerable to biases, places more weight on young-age deaths, and has been recognized as a more advanced measure for evaluating the health effects of exposure or intervention (Cheng et al., 2021; Connolly et al., 2023; Lai and Hardy, 1999). Recently, an increasing number of studies used YLL to assess the life expectancy of exposure to urban environment (e.g., air pollution, heat waves, and cold temperature) (Cheng et al., 2021; Moran et al., 2021; Qi et al., 2020). However, no research has examined the effects of greenspace exposure on the life expectancy of elderly population at the individual level in China.

To address the above research gaps, this study employed the individual-level mortality dataset of elderly population in Guangzhou, China, in 2010 and comprehensively explored the relationship between greenspace exposure and life expectancy. The four objectives were as follows: 1) to examine the relationship between neighborhood greenspace exposure and life expectancy at the individual level; 2) to explore whether neighborhood greenspace exposure has higher effects on life expectancy for socioeconomically disadvantaged individuals (equigenesis hypothesis); 3) to investigate the optimal buffer distances of neighborhood greenspace exposure with life expectancy for elderly population; 4) to compare the results from different measures of greenspace exposure (Fig. 1).

Our research extends existing studies in several aspects. First, this is one of the first research to uncover the impact of greenspace exposure on life expectancy at the individual level in a densely populated Chinese context. This study can avoid ecological fallacy and offer more rigorous evidence compared with the studies using aggregate-level data (Hong et al., 2021; R. Mitchell and Popham, 2008; Moran et al., 2021), examining the effect of greenness and equigenesis hypothesis on life expectancy. Second, by investigating the optimal buffer distances, we can explore the optimal distances of greenspace exposure between neighborhood greenspace exposure and elderly life expectancy, thereby providing support and design strategies for age-friendly urban design and management. Third, by comparing different greenspace measurements, we can ascertain whether greenspace measurements are a potential contributor to the inconsistent results and offer suggestions for future greenspace-health research that involves measuring greenspaces.

2. Methodology

Guangzhou, one of China's most populous cities with rapid urbanization, has abundant natural elements, such as forests, lakes, and hills, offering a variety of greenspaces in terms of uses, types, and sizes (Fig. 2). Considering the availability of mortality data from Guangzhou in 2010, we selected Guangzhou as the study area and collected multi-source built environment data in 2010 to examine the effect of greenspace exposure on life expectancy.

2.1. Measures

2.1.1. Life expectancy

This study obtained the anonymized and individual mortality dataset of elderly people (larger than 60 years) in 2010 from the National Health Commission of Guangzhou. This dataset includes 21,736 records of registered deaths with the information of age at death, education level, sex, residence location, career, and cause of death. We considered all causes of non-accidental deaths (ICD-10: A00-R99) based on the Tenth Revision codes (ICD-10) provided by WHO International Classification of Diseases (World Health Organization [WHO], 2004).

Fig. 1. Three methods for greenspace exposure measuring. (a) Measured with fishnet units (or district, zip code); (b) Measured with straight-line buffer; (c) Measured with street-network buffer. Aggregate measure (a) (e.g., fishnet units, district, zip code) is typically used in collective greenspace-mortality studies but may be affected by ecological fallacy and lead to inconsistencies and misinformation. Straight-line buffer (b) is typically used in individual greenspace-mortality studies, assuming that individuals can walk around freely within the buffer. Street-network buffer (c) considers the street network with a more detailed representation of the area around the individual.

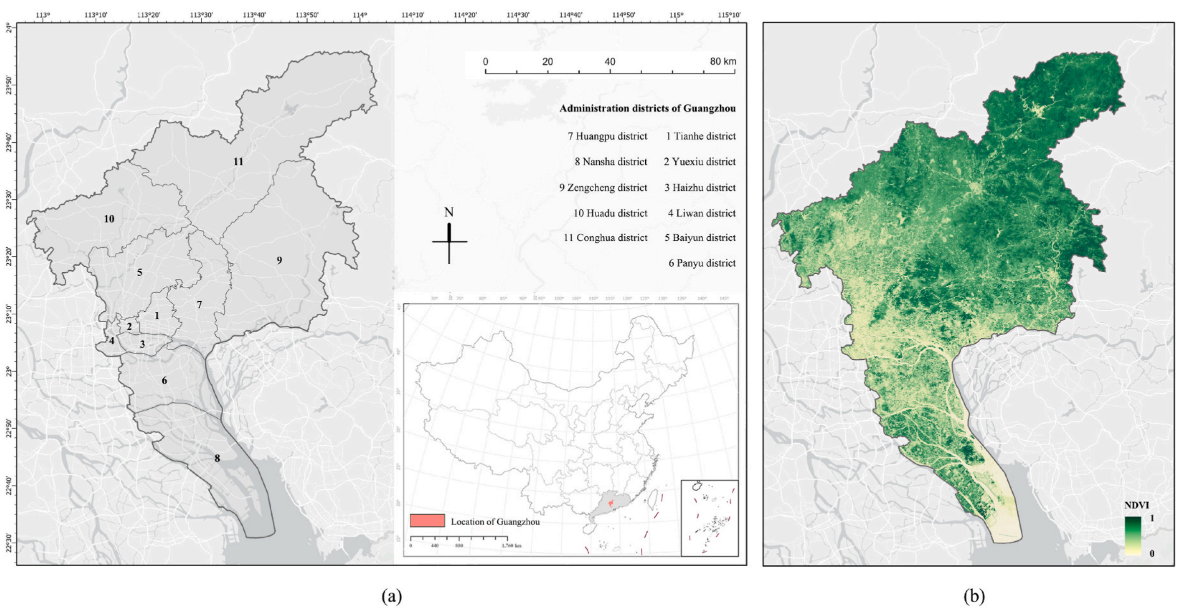

Fig. 2. The maps of Guangzhou, China. (a) The illustration of Guangzhou location and administration districts; (b) The greenspace coverage of Guangzhou in 2010, measured by NDVI.

Life expectancy represents the average age a person is expected to live according to gender and age-specific mortality rates. Following the calculation methods and data sources used in existing research (Cheng et al., 2021; Guo et al., 2013; Qi et al., 2020), we employed YLL to quantify the life expectancy loss using the Chinese Life Table. This table was produced by (World Health Organization [WHO], 2010); it provides values of e_x (the average number of years of life remaining expected by people at a given age) and the variables to calculate YLL. The details of the Chinese Life Table are described in Table S1 (Supplementary Material). We matched the YLL value for each death by age and sex. This study has been approved by City University of Hong Kong Research Committee (Human Research Ethics).

2.1.2. Greenspace exposure

We quantified the greenspace coverage based on the normalized difference vegetation index (NDVI) through remote sensing. NDVI is a widely adopted method for measuring the quantity of greenspace coverage at the pixel level. The 30-m resolution Landsat-5 satellite images at no cloud period from January 1 to December 31, 2010, were employed to calculate the NDVI of Guangzhou on Google Earth Engine (GEE) with the average - value procedure (Gorelick et al., 2017). Considering that negative NDVI values typically indicate water or snow, we assigned values of 0 to all pixels with negative NDVI values before applying the averaging procedure (Lillesand et al., 2015). NDVI value (Fig. 2b) was measured by the near-infrared band (NIR) and the red band (R) via the following equation:

$$NDVI = \frac{NIR - R}{NIR + R}$$

To measure the greenspace exposure, we used three methods, namely fishnet units, straight-line buffer, and street-network buffer. In detail, fishnet units measure the greenspace exposure at the aggregate level; we used a 1 km × 1 km fishnet of square grids covering the entire Guangzhou area. The average YLL of all subjects residing within a grid was used as the outcome, while the average NDVI within a grid was used to assess greenspace exposure.

In addition, straight-line and street-network buffers measure greenspace exposure at the individual level. The straight-line buffer defines a circular area of exposure around a person's residence within walking distance. The street-network buffer defines the accessible exposure within walking distance, as it excludes the environments that are inaccessible, such as closed-off courtyards, places obstructed by transportation infrastructure, and inaccessible natural features (e.g., rivers). We used the street vector data of Guangzhou in 2010; after eliminating streets/roads that people cannot walk on (e.g., highway, viaduct), we calculated the street-network buffer via the network analysis in ArcGIS Pro 2.9.1.

For accurately evaluating the greenspace exposure at walking distances, we calculated the straight-line buffer and street-network buffer with varying buffer sizes. Following previous research (Jiang et al., 2022), we examined the effects of greenspace exposure ranging from 200 m to 4 km, setting the buffer intervals of 200 m for distances up to and including 2 km (e.g., 200 m, 400, 600, …, 2 km) and 500 m for buffers between 2 and 4 km (2.5 km, 3, 3.5, 4). Greenspace exposure for individuals was evaluated by averaging NDVI value within a buffer.

The above exposure areas (i.e., fishnet units, straight-line, and street-network buffers) were calculated in ArcGIS Pro 2.9.1, and the calculations of greenspace exposure were performed in GEE.

2.1.3. Socioeconomic status (SES) variables

To examine whether greenspace exposure has higher effects on life expectancy for socioeconomically disadvantaged individuals (or the equigenesis hypothesis), we included an individual-level SES variable in the models. Since household income is not available in this dataset, we followed previous studies and used education level as a proxy of individual SES because they are highly associated (Aikens and Barbarin, 2008; J. Liu et al., 2020; Moran et al., 2021). Education levels were categorized into four levels (R. Wang et al., 2022): college or above, middle school or above, primary school, and illiterate (not able to read or write) or semi-literate (barely able to read or write); their proportions were 7.74%, 31.43%, 37.49%, and 23.33%, respectively.

2.1.4. Covariates

Following the existing studies (R. Mitchell and Popham, 2008; R. Wang et al., 2022), we controlled for individual and built environment covariates. The individual covariates include four variables: sex, marriage status, career, and urban or rural classification; the built environment covariates include six variables: road density, road intersection, medical service density, point of interest (POI) density, POI richness, and POI entropy. In addition, the surrounding pollutants ($PM_{2.5}$ and PM_{10}) and population density in 2010 were also controlled in this study. All variables under different exposure methods were calculated; Table 1 illustrates the summary of descriptive statistics. Detailed calculation of covariates can be found in Supplementary Materials.

Table 1
Descriptive statistics.

Variables	Proportion/Mean (SD)					Data source (spatial unit)
	Fishnet unit	Straight-line buffer		Street-network buffer		
	1 x 1km	800 m	1600 m	800 m	1600 m	
Outcome						
Year of life lost (YLL) (year)	9.77 (1.96)	13.64 (10.50)				The mortality dataset of elderly people in 2010 Guangzhou (geographic vector data)
Predictor						
NDVI	0.26 (0.12)	0.18 (0.10)	0.19 (0.10)	0.17 (0.09)	0.18 (0.09)	Landsat-5 satellite images from January 1 to December 31, 2010 (30 × 30 m)
SES variable						
Education level						The mortality dataset of elderly people in 2010 Guangzhou (geographic vector data)
College or above	0.04 (0.10)	7.74%				
Middle school or above	0.18 (0.18)	31.43%				
Primary school	0.44 (0.25)	37.49%				
Illiterate or semi-literate	0.34 (0.26)	23.33%				
Individual covariates						
Sex						
Male	0.542 (0.204)	56.97%				
Female	0.458 (0.204)	43.03%				
Marital status						
Single	0.03 (0.07)	4.15%				
Married	0.69 (0.22)	68.81%				
Divorced or widowed	0.29 (0.21)	27.04%				
Career						
Unemployed	0.21 (0.26)	22.99%				
Employed	0.79 (0.26)	77.01%				
Built environment covariates						
Type of area						The urban boundary data of Guangzhou in 2010 (geographic vector data)
Urban area	57.0%	75.08%				
Rural area	43.0%	24.92%				
Road density (length of road (km) per area)	6.46 (5.16)	10.77 (5.14)	9.37 (4.05)	14.754 (6.358)	13.472 (3.974)	The road data of Guangzhou in 2010 from Baidu Maps (geographic vector data)
Road intersection (road intersection number per area)	40.66 (37.91)	127.02 (67.88)	464.40 (239.46)	75.412 (44.915)	271.84 (151.16)	
Medical service density (medical service number per area)	8.70 (12.67)	43.16 (32.12)	151.11 (110.59)	27.208 (22.317)	97.209 (76.467)	The POI data of Guangzhou in 2010 from Baidu Maps (geographic vector data)
POI density (POI number per area)	121.95 (201.53)	797.07 (684.11)	2807.90 (2294.10)	503.62 (470.50)	1815.04 (1597.85)	
POI richness	5.01 (2.94)	7.04 (2.05)	7.42 (1.53)	6.91 (2.18)	7.27 (1.78)	
POI entropy	0.69 (0.35)	0.82 (0.20)	0.85 (0.12)	0.80 (0.22)	0.84 (0.16)	
Control variables						
Population density (1000 people per area)	4.44 (8.84)	39.78 (35.53)	152.26 (123.93)	20.53 (19.80)	84.63 (75.25)	WorldPop Global Project Population Dataset in 2010 (100 × 100 m)
$PM_{2.5}$ ($\mu g/m^3$)	44.89 (2.24)	46.10 (1.81)	46.08 (1.82)	46.11 (1.81)	46.10 (1.81)	Ground-level PM2.5 and PM10 Dataset for China (1 x 1 km)
PM_{10} ($\mu g/m^3$)	69.29 (4.00)	71.70 (3.33)	71.64 (3.34)	71.71 (3.32)	71.70 (3.32)	

2.2. Statistical analysis

This study used linear mixed models to investigate the associations between greenspace exposure and life expectancy. Before running modeling, we employed the variance inflation factor (VIF) test to eliminate the potential multicollinearity of variables. PM_{10} was excluded due to high multicollinearity; the VIF value of other variables is less than 4, suggesting that there was no significant multicollinearity in our model (O'brien, 2007). The natural logarithm was used for YLL to fit into a normal distribution (Benoit, 2011). Considering the differences in socio-economic levels between different administrative districts in Guangzhou, the random intercept for different administrative districts was adjusted in our model to examine the random effect in diverse urban contexts. The fixed effect of greenspace exposure on life expectancy was then evaluated after adjusting for covariates.

We performed multiple models to examine the four objectives. First, Model 1 to Model 5 examined the direct effect of greenspace exposure on life expectancy under different measurement methods (i.e., fishnet unit, straight-line buffer, and street-network buffer) (Objective 1). In reporting the greenspace effect using individual measurements, we initially report results with buffers of 800 m and 1600 m, which are typically employed in walking/cycling built environment research (Jiang et al., 2022; Yang et al., 2020). All independent variables were standardized by centering them at their mean and scaling them by their respective standard deviation (SD). Coefficients of NDVI for the YLL are interpreted as changes in logged YLL per one SD change of greenness. Negative coefficients represent a negative effect on life expectancy loss or a positive effect on life expectancy, and vice versa.

Second, Model 6 to Model 10 added the interaction terms between greenspace exposure and SES (NDVI x education level) to assess the moderation effect under different measurement methods (Objective 2). The interaction coefficients between NDVI and education level are the changes in the effect of SES on YLL per one SD change in greenness. If the interaction terms are significant and the group of lower education levels received a larger and more beneficial effect of NDVI on YLL, then the equigenesis hypothesis is supported by our findings.

Table 2
The linear mixed models for the relationship between greenspace exposure and life expectancy loss. The significant effects of greenspaces were found in both aggregate (Model 1) and individual measures (Models 2 to 5). The methodology for calculating greenspace exposure can be found in Section 2.1.2.

Variables	Model 1 (1 × 1 km fishnet units)		Model 2 (800-m straight-line buffer)		Model 3 (800-m street-network buffer)		Model 4 (1600-m straight-line buffer)		Model 5 (1600-m street-network buffer)	
	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value
Fixed part										
Predictor										
NDVI	−0.03 (0.01)	0.008 **	−0.04 (0.02)	0.018 *	−0.04 (0.02)	0.020 *	−0.06 (0.02)	<0.001 ***	−0.05 (0.02)	0.009 **
SES variable										
Middle school or above (ref. group = College or above)	0.02 (0.02)	0.205	0.14 (0.03)	<0.001 ***	0.14 (0.03)	<0.001 ***	0.14 (0.03)	<0.001 ***	0.14 (0.03)	<0.001 ***
Primary school (ref. group = College or above)	−0.02 (0.02)	0.386	−0.14 (0.03)	<0.001 ***	−0.14 (0.03)	<0.001 ***	−0.13 (0.03)	<0.001 ***	−0.14 (0.03)	<0.001 ***
Illiterate or semi-literate (ref. group = College or above)	−0.04 (0.02)	0.089	−0.42 (0.03)	<0.001 ***	−0.42 (0.03)	<0.001 ***	−0.42 (0.03)	<0.001 ***	−0.42 (0.03)	<0.001 ***
Individual covariates										
Female (ref. group = Male)	−0.01 (0.01)	0.161	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***
Married (ref. group = Single)	−0.01 (0.02)	0.745	0.03 (0.04)	0.428	0.03 (0.04)	0.429	0.03 (0.04)	0.498	0.03 (0.04)	0.465
Divorced or widowed (ref. group = Single)	−0.04 (0.02)	0.049 *	−0.58 (0.04)	<0.001 ***	−0.58 (0.04)	<0.001 ***	−0.59 (0.04)	<0.001 ***	−0.58 (0.04)	<0.001 ***
Employed (ref. group = Unemployed)	0.00 (0.01)	0.781	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***
Built environment covariates										
Urban area (ref. group = Rural area)	0.04 (0.02)	0.086	−0.00 (0.02)	0.973	−0.00 (0.02)	0.86	−0.00 (0.02)	0.936	−0.00 (0.02)	0.996
Road density	−0.01 (0.01)	0.213	−0.06 (0.03)	0.022 *	−0.02 (0.01)	0.093	−0.10 (0.04)	0.016 *	−0.04 (0.01)	0.002 **
Road intersection	0.01 (0.01)	0.543	0.05 (0.02)	0.037 *	0.02 (0.01)	0.167	0.08 (0.03)	0.009 **	0.04 (0.02)	0.007 **
Medical service density	0.01 (0.01)	0.664	0.01 (0.01)	0.546	0.01 (0.01)	0.181	−0.00 (0.02)	0.885	−0.01 (0.02)	0.505
POI density	−0.02 (0.01)	0.224	−0.05 (0.01)	<0.001 ***	−0.05 (0.01)	<0.001 ***	−0.05 (0.02)	0.019 *	−0.06 (0.02)	0.001 **
POI richness	0.00 (0.02)	0.965	0.03 (0.01)	0.029 *	0.01 (0.02)	0.510	0.03 (0.01)	0.020 *	0.03 (0.01)	0.037 *
POI entropy	0.01 (0.01)	0.521	−0.01 (0.01)	0.212	0.00 (0.01)	0.717	0.00 (0.01)	0.984	−0.00 (0.01)	0.953
Control variables										
Population density	−0.01 (0.01)	0.224	0.00 (0.01)	0.646	0.01 (0.01)	0.482	−0.00 (0.01)	0.811	0.00 (0.01)	0.853
$PM_{2.5}$	0.04 (0.01)	0.002 **	0.08 (0.02)	<0.001 ***	0.08 (0.02)	<0.001 ***	0.09 (0.02)	<0.001 ***	0.08 (0.02)	<0.001 ***
Random part										
σ^2	0.03		0.86		0.86		0.86		0.86	
τ00 (administration district)	0.01		0.01		0.01		0.01		0.01	
ICC	0.03		0.01		0.01		0.01		0.01	
N (administration district)	11		11		11		11		11	
Observations	837		21,736		21,736		21,736		21,736	
AIC	−439.21		58641.75		58253.64		58227.64		58236.44	

Notes: 1) All coefficients in the table are standardized coefficients; 2) *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Third, Model 11 and Model 12 examined the dose-response effect of greenspace exposure and the interaction terms at buffer distances ranging from 200 m to 4000 m (Objective 3).

Fourth, we compared the results from different greenspace measurements in Model 1 to 12 to examine the differences in results between aggregate and individual measurements and the differences in results between individual measurements (i.e., straight-line buffer and street-network buffer) (Objective 4).

The above models allow us to carefully examine the effect of greenspace on life expectancy and the differences in the effects under different exposure measures. In all models, we reported the standardized coefficients to compare the effect of independent variables on YLL. All statistical analyses were performed in R v4.0.5.

3. Results

3.1. Associations between greenspace exposure and life expectancy

Model 1 to 5 presented the association between greenspace exposure and life expectancy among elderly individuals at both aggregate and

Table 3
The linear mixed models for the relationship between greenspace exposure and life expectancy loss with interaction terms. Model 6 used an aggregate measure of greenspace exposure, while Models 7 to 10 used individual measures. The significant moderation effects of greenspaces were found only in individual measures (Models 7 to 10).

Variables	Model 6 (1 × 1 km fishnet units)		Model 7 (800-m straight-line buffer)		Model 8 (800-m street-network buffer)		Model 9 (1600-m straight-line buffer)		Model 10 (1600-m street-network buffer)	
	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value	Coef. (SE)	P-value
Fixed part										
Predictor										
NDVI	−0.01 (0.01)	0.408	0.03 (0.04)	0.469	0.02 (0.04)	0.637	0.02 (0.05)	0.667	0.04 (0.05)	0.420
SES variable										
Middle school or above (ref. group = College or above)	0.02 (0.02)	0.188	0.1 (0.03)	<0.001 ***	0.11 (0.03)	<0.001 ***	0.1 (0.03)	0.001 **	0.1 (0.03)	0.002 **
Primary school (ref. group = College or above)	−0.01 (0.02)	0.508	−0.18 (0.03)	<0.001 ***	−0.17 (0.03)	<0.001 ***	−0.18 (0.03)	<0.001 ***	−0.18 (0.03)	<0.001 ***
Illiterate or semi-literate (ref. group = College or above)	−0.03 (0.02)	0.127	−0.45 (0.03)	<0.001 ***	−0.44 (0.03)	<0.001 ***	−0.45 (0.03)	<0.001 ***	−0.45 (0.03)	<0.001 ***
Individual covariates										
Female (ref. group = Male)	−0.01 (0.01)	0.143	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***	0.12 (0.01)	<0.001 ***
Married (ref. group = Single)	−0.01 (0.02)	0.745	0.03 (0.04)	0.442	0.03 (0.04)	0.437	0.03 (0.04)	0.515	0.03 (0.04)	0.469
Divorced or widowed (ref. group = Single)	−0.04 (0.02)	0.049 *	−0.58 (0.04)	<0.001 ***	−0.58 (0.04)	<0.001 ***	−0.59 (0.04)	<0.001 ***	−0.58 (0.04)	<0.001 ***
Employed (ref. group = Unemployed)	0.00 (0.01)	0.879	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***	0.06 (0.02)	<0.001 ***
Built environment covariates										
Urban area (ref. group = Rural area)	0.04 (0.02)	0.065	0.0 (0.02)	0.979	−0.0 (0.02)	0.875	−0.0 (0.02)	0.965	0.0 (0.02)	0.970
Road density	−0.01 (0.01)	0.224	−0.06 (0.03)	0.023 *	−0.02 (0.01)	0.090	−0.1 (0.04)	0.012 *	−0.05 (0.01)	0.001 **
Road intersection	0.01 (0.01)	0.458	0.04 (0.02)	0.050	0.02 (0.01)	0.195	0.08 (0.03)	0.009 **	0.04 (0.02)	0.009 **
Medical service density	0.01 (0.01)	0.507	0.01 (0.01)	0.515	0.01 (0.01)	0.166	−0.0 (0.02)	0.873	−0.01 (0.02)	0.526
POI density	−0.02 (0.01)	0.235	−0.05 (0.01)	<0.001 ***	−0.04 (0.01)	<0.001 ***	−0.05 (0.02)	0.028 *	−0.06 (0.02)	0.001 **
POI richness	0.01 (0.02)	0.642	0.03 (0.02)	0.072	0.01 (0.02)	0.733	0.02 (0.01)	0.043 *	0.02 (0.01)	0.085
POI entropy	0.00 (0.01)	0.633	−0.01 (0.01)	0.251	0.0 (0.01)	0.685	−0.0 (0.01)	0.986	−0.0 (0.01)	0.983
Control variables										
Population density	−0.01 (0.01)	0.292	0.01 (0.01)	0.555	0.01 (0.01)	0.429	−0.0 (0.01)	0.962	0.0 (0.01)	0.751
$PM_{2.5}$	0.03 (0.01)	0.023 *	0.08 (0.02)	<0.001 ***	0.08 (0.02)	<0.001 ***	0.1 (0.02)	<0.001 ***	0.08 (0.02)	<0.001 ***
Interaction terms										
NDVI * Middle school or above (ref. group = College or above)	−0.01 (0.02)	0.656	−0.06 (0.05)	0.174	−0.05 (0.05)	0.277	−0.08 (0.05)	0.090	−0.08 (0.05)	0.110
NDVI * Primary school (ref. group = College or above)	−0.01 (0.02)	0.554	−0.06 (0.04)	0.179	−0.05 (0.05)	0.319	−0.07 (0.04)	0.098	−0.07 (0.05)	0.126
NDVI * Illiterate or semi-literate (ref. group = College or above)	−0.01 (0.03)	0.682	−0.11 (0.05)	0.016 *	−0.09 (0.05)	0.049 *	−0.13 (0.05)	0.005 **	−0.12 (0.05)	0.014 *
Random part										
σ^2	0.03		0.86		0.86		0.86		0.86	
τ00 (administration district)	0.01		0.01		0.01		0.01		0.01	
ICC	0.03		0.01		0.01		0.01		0.01	
N (administration district)	11		11		11		11		11	
Observations	837		21,736		21,736		21,736		21,736	
AIC	−427.58		58394.91		58490.66		58378.97		58390.57	

Notes: 1) All coefficients in the table are standardized coefficients; 2) *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

individual measures (Table 2). After controlling for the covariates, the results of both aggregate and individual measures showed significant and negative associations between greenspace exposure and life expectancy loss.

3.2. Associations between SES of elderly individuals and the effects of greenspace exposure

Model 6 to 10 illustrated the moderation effect of SES on the relationship between greenspace exposure and life expectancy (Table 3). Although the interaction term (NDVI x SES) was not significant in the aggregate measure (Model 6), the interaction terms in the individual measures (i.e., straight-line buffer and street-network buffer with 800 m and 1600 m buffer sizes) (Model 7 to 10) were all significant. The results indicated that the SES significantly moderated the relationship between greenspace exposure and life expectancy in the individual measures. The elderly individuals with lower SES (illiterate or semi-literate) had a significantly higher effect of greenspace exposure on life expectancy than those with higher SES (college or above) (Fig. 3). It supports the equigenic effect, i.e., the greenspaces are more beneficial for socially disadvantaged groups.

3.3. Associations of exposure to greenspace at varying buffer distances with life expectancy and equigenesis

First, we investigated the direct effects of greenspace exposure at various buffer sizes in different individual measures within walking distance (100 m–4 km) on life expectancy. The results showed that all direct effects are significant, demonstrating the robustness of the effects of greenspaces.

Greenspace exposure was significantly negatively associated with life expectancy loss from 200 m to 4 km (Table 4). The exposure buffer-response curve (Fig. 4) illustrated that the effect of greenspace, as measured by straight-line and street-network buffers, increased with the buffer size and reached its highest value at 2500 m (−0.07, $p < 0.001$) and 3000 m (−0.09, $p < 0.001$), respectively.

Table 4
The fixed effect of greenspace exposure in different buffer sizes after controlling for covariates and random effects (Model 11). The negative coefficients can be interpreted as either negative effects of greenspace exposure on life expectancy loss or positive effects of greenspace exposure on life expectancy.

Buffer size (m)	Straight-line buffer		Street-network buffer	
	Coef. (SE)	P-value	Coef. (SE)	P-value
200	−0.04 (0.01)	0.001 **	−0.03 (0.01)	0.005 **
400	−0.04 (0.01)	0.005 **	−0.04 (0.01)	0.003 **
600	−0.04 (0.02)	0.02 *	−0.04 (0.01)	0.009 **
800	−0.04 (0.02)	0.018 *	−0.04 (0.02)	0.02 *
1000	−0.05 (0.02)	0.004 **	−0.03 (0.02)	0.037 *
1200	−0.06 (0.02)	0.001 **	−0.04 (0.02)	0.029 *
1400	−0.06 (0.02)	0.001 **	−0.04 (0.02)	0.037 *
1600	−0.06 (0.02)	<0.001 ***	−0.05 (0.02)	0.009 **
1800	−0.07 (0.02)	<0.001 ***	−0.05 (0.02)	0.003 **
2000	−0.06 (0.02)	0.001 **	−0.06 (0.02)	0.002 **
2500	−0.07 (0.02)	<0.001 ***	−0.07 (0.02)	<0.001 ***
3000	−0.06 (0.02)	0.01 *	−0.09 (0.02)	<0.001 ***
3500	−0.06 (0.02)	0.013 *	−0.08 (0.02)	<0.001 ***
4000	−0.06 (0.02)	0.006 **	−0.08 (0.02)	<0.001 ***

Notes: 1) All coefficients in the table are standardized coefficients; 2) *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

Next, we investigated the equigenic effects of greenspace exposure at various buffer sizes in different individual measures within walking distance (100 m–4 km) on life expectancy. The results showed that all interaction terms of NDVI x Illiterate or semi-literate are significant from 200 m to 4 km (Table 5), demonstrating the robustness of the equigenesis effects of greenspaces.

The exposure buffer-response curve (Fig. 5) showed that the effect of interaction term increases with buffer size for straight-line and street-network buffers, peaking at 1600 m (−0.13, $p < 0.01$) and 2500 m (−0.14, $p < 0.01$), respectively. The disparities in greenspace effects between different SES groups are most pronounced at the 2500 m street-network buffer (Fig. 6), where the interaction effect peaks.

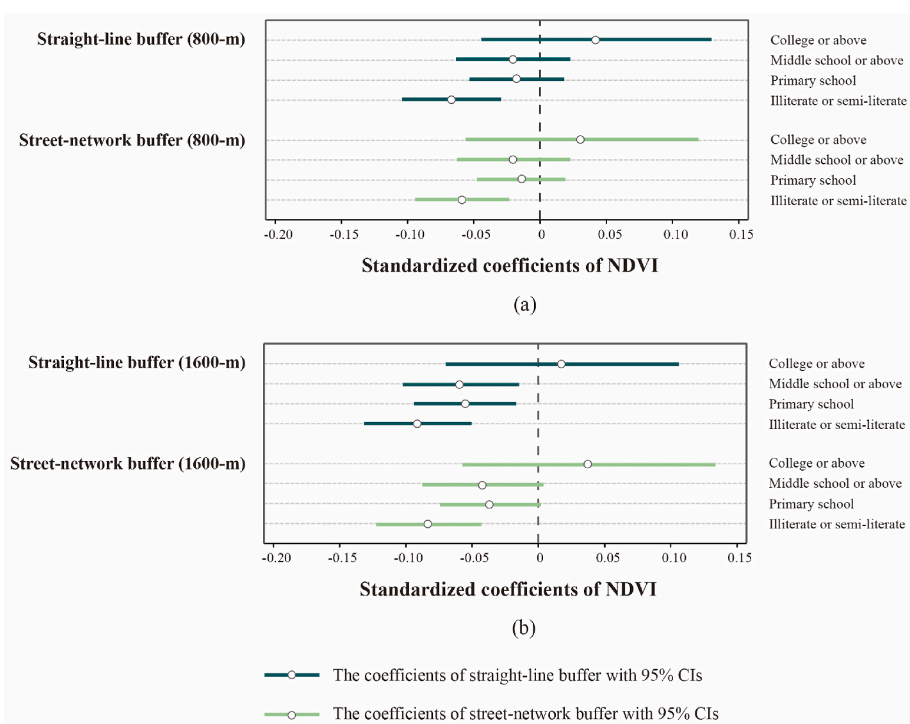

Fig. 3. SES moderates the effect of greenspace exposure on life expectancy loss with different buffer sizes. (a) The result with a buffer size of 800 m; (b) The result with a buffer size of 1600 m.

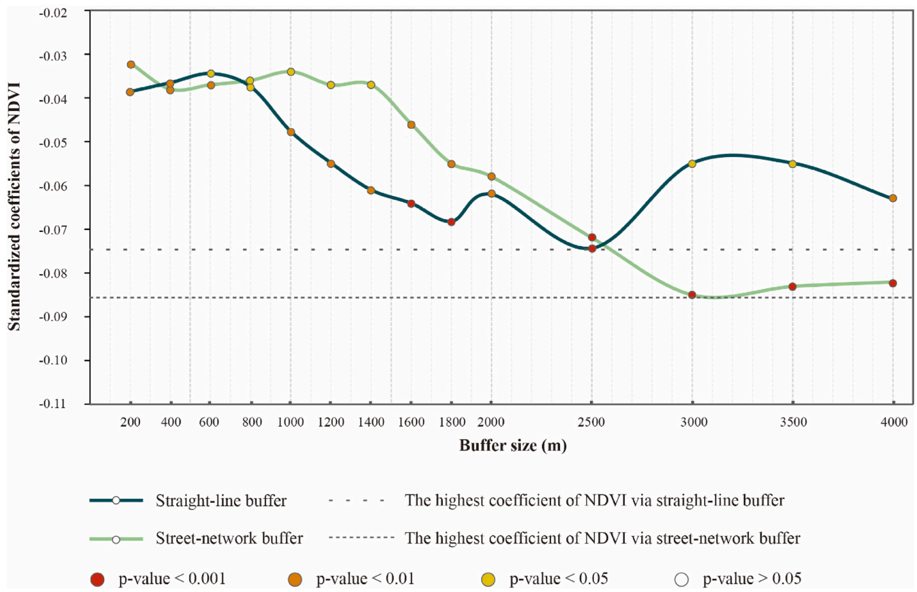

Fig. 4. The effects of greenspace exposure within walking distance (100 m–4 km) on life expectancy loss. The highest effect of greenspace exposure for straight-line buffer and street-network buffer is greatest at 2500 m and 3000 m, respectively; the effect for street-network buffer is higher than that for straight-line buffer.

Table 5
The fixed effect of the interaction term (NDVI x Illiterate or semi-literate [ref. group = College or above]) in different buffer sizes after controlling for covariates and random effects (Model 12). The coefficients of interaction terms can be interpreted as the differences in the effects of greenspace exposure on the life expectancy loss of illiterate or semi-literate and college or above.

Buffer size (m)	Straight-line buffer		Street-network buffer	
	Coef. (SE)	P-value	Coef. (SE)	P-value
200	−0.07 (0.04)	0.07	−0.09 (0.04)	0.023 *
400	−0.11 (0.04)	0.011 *	−0.1 (0.04)	0.019 *
600	−0.1 (0.04)	0.02 *	−0.09 (0.04)	0.035 *
800	−0.11 (0.05)	0.016 *	−0.09 (0.05)	0.049 *
1000	−0.12 (0.05)	0.009 **	−0.09 (0.05)	0.049 *
1200	−0.13 (0.05)	0.006 **	−0.1 (0.05)	0.03 *
1400	−0.13 (0.05)	0.005 **	−0.11 (0.05)	0.023 *
1600	−0.13 (0.05)	0.005 **	−0.12 (0.05)	0.014 *
1800	−0.12 (0.05)	0.008 **	−0.13 (0.05)	0.007 **
2000	−0.11 (0.05)	0.015 *	−0.14 (0.05)	0.004 **
2500	−0.09 (0.05)	0.045 *	−0.14 (0.05)	0.004 **
3000	−0.08 (0.05)	0.089	−0.13 (0.05)	0.007 **
3500	−0.08 (0.05)	0.081	−0.12 (0.05)	0.019 *
4000	−0.08 (0.05)	0.068	−0.12 (0.05)	0.024 *

Notes: 1) All coefficients in the table are standardized coefficients; 2) *: $p < 0.05$, **: $p < 0.01$, ***: $p < 0.001$.

3.4. Differences in results from different greenspace measurement methods

Our results showed that the different greenspace measurements affect the effect of greenspace exposure on life expectancy and equigenesis. In detail, the interaction term exhibited insignificance through aggregate measures but displayed significance across all individual measures. The mixed results may be attributed to the ecological fallacy bias in the aggregate-level analysis.

In addition, we found the varied effects of greenspace exposure caused by different individual measures. The effect of greenspace exposure was higher when measured by the street-network buffer (−0.09, $p < 0.001$) than by the straight-line buffer (−0.07, $p < 0.001$). Similarly, the effect of interaction terms was higher when measured by the street-network buffer (−0.14, $p < 0.01$) than by the straight-line buffer (−0.13, $p < 0.01$). This suggested that using the straight-line buffer as the individual measurement may underestimate the effects of greenspace exposure on life expectancy and equigenesis.

4. Discussion

Our findings extend previous studies exploring the association between greenspaces and health outcomes (Rojas-Rueda et al., 2019), especially the equigenesis hypothesis (i.e., the effect of greenspaces is higher among the socially disadvantaged groups). First, to our best knowledge, this is the first citywide research to examine the relationship between greenspace exposure and life expectancy at the individual level within a densely populated Chinese context. It offers novel theoretical perspectives regarding the generalizability of the greenspaces' effects beyond previously studied low- and medium-density cities in high-income countries because high-density cities in China feature unique demographic, social, and health contexts compared with previously studied cities. Additionally, it focuses on the life expectancy of elderly individuals in China, with great potential to deal with the challenges posed by the aging population in China and other places in the world. Second, on the methodological front, it confirms that the different greenspace measurements at least partly contribute to the inconsistency of the existing evidence, as demonstrated by the different results of three greenspace measurements. Therefore, it is necessary to use standardized and/or multiple measurements of greenspace for future greenspace-related studies. Third, this study reveals the optimal buffer zones of greenspaces' effects, which offers more specific evidence to guide urban design and management.

4.1. Interpretation of key findings

4.1.1. The effect of greenspace exposure on life expectancy

Our findings indicated a significant association between higher greenspace exposure and lower life expectancy loss among elderly adults, aligning with previous research demonstrating that higher greenspace exposure is related to lower all-cause mortality rates (Markevych et al., 2017; Rojas-Rueda et al., 2019; Twohig-Bennett and Jones, 2018). We used the YLL metric for measuring life expectancy, which is a more informative measure than mortality rate as it considers sex and age of life expectancy at the time of death, with particular emphasis on premature death in relatively younger elderly adults (Cheng et al., 2021; Guo et al., 2013; Moran et al., 2021; Qi et al., 2020).

In addition, existing studies typically examined the effect of

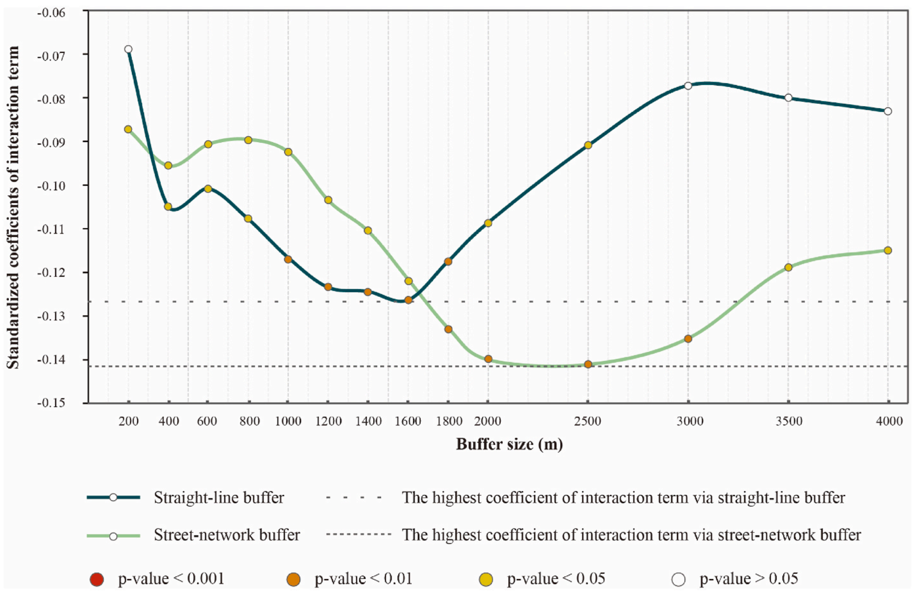

Fig. 5. The effects of the interaction term (NDVI * Illiterate or semi-literate) with comfortable walking distance (100 m–4 km) on life expectancy loss. The highest effect of the interaction term (i.e., the highest difference in the effect of inter-group) for straight-line buffer and street-network buffer is greatest at 1600 m and 2500 m, respectively; the difference in effect for street-network buffer is higher than that for straight-line buffer.

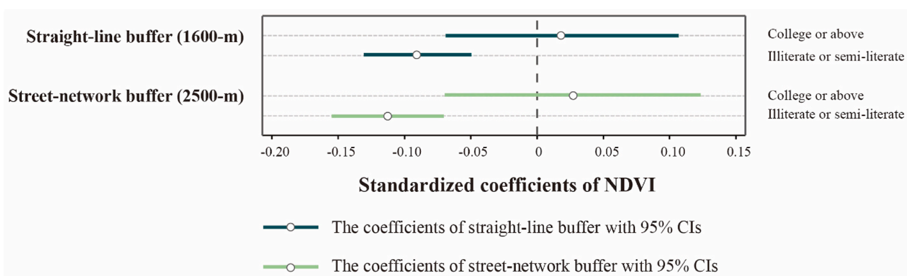

Fig. 6. The highest moderating effects of SES (NDVI x Illiterate or semi-literate [ref. group = College or above]) on the relationship between greenspace exposure and life expectancy loss in the straight-line buffer (1600-m) and street-network buffer (2500-m), respectively.

greenspace on mortality at either the aggregate level (R. Mitchell and Popham, 2008) or the individual level with a few straight-line buffers (e.g., 300-m and 1000-m) (Orioli et al., 2019). However, our study demonstrated the significance of greenspace exposure not only at the aggregate level but also at the individual level across various buffer types (straight-line and street network buffers). Importantly, these significant effects persist across the entire range of pedestrian-friendly buffer distances from 200 to 4000 m. This not only emphasized the robustness of our findings but also revealed that greenspace exposure, whether in aggregate, individually, or in various exposure buffers, consistently yields positive effects on the life expectancy of elderly individuals.

The health benefits resulting from greenspaces that contribute to lower life expectancy loss can be explained via three major underlying pathways, as proposed by (Markevych et al., 2017). 1) Reducing harm. Higher greenspaces have been confirmed to have significant associations with lower air pollution, urban heat islands, and traffic noise (Markevych et al., 2017). 2) Restoring capacities. According to stress reduction theory (SRT) and attention restoration theory (ART), greenspaces may improve mental health by promoting attention restoration and facilitating stress recovery processes (Markevych et al., 2017; R. Wang et al., 2022). 3) Building capacities. Greenspaces may encourage physical activity and facilitate a sense of community. These spaces can inspire physical activity by improving the aesthetics of outdoor exercise spaces (e.g., parks and streets) and making the general neighborhood environment more attractive (Lu et al., 2018). In addition, greenspaces offer a setting for neighborly interactions that may foster social connectedness and augment a collective sense of cohesion within a community (Markevych et al., 2017).

Moreover, we discovered that the effects of greenspace in street-network buffer were higher than in straight-line buffer. This suggests that greenspaces that are accessible have greater effects on life expectancy compared to greenspaces that are inaccessible. However, inaccessible greenspaces can also confer health benefits via ecosystem services (e.g., air cleaning, heat buffering), though evidence indicates that the effect of the reducing harm pathway, while significant, is typically small in magnitude (Nieuwenhuijsen et al., 2017).

4.1.2. The effect of greenspace exposure on equigenesis

Our findings indicated that the Chinese elderly population with disadvantaged SES may benefit more from greenspaces with respect to life expectancy improvements. The observation aligns with the previous studies demonstrating the equigenesis hypothesis of greenspace (R. Mitchell and Popham, 2008; Rigolon et al., 2021). Most of these studies have focused on North America, Europe, and the United Kingdom, primarily using mortality instead of life expectancy as the outcome measure (Rigolon et al., 2021). Hence, our study contributes to the existing research by providing citywide evidence of the equigenic effect of greenspace on life expectancy in a high-density city in China.

Furthermore, existing meta-analyses suggested that lower-income groups in economically disadvantaged regions may gain more health benefits from greenspace exposure (Rigolon et al., 2021). However, a recent aggregate-level study on life expectancy in Latin America has shown mixed or insignificant results (Moran et al., 2021). This inconsistency may be explained by different ways to measure such effect (individual-level vs. aggregate-level). As demonstrated in this study, the equigenic effect of greenspace exposure was insignificant at the aggregate level, and the effects at the individual level were significant across various buffer types and all buffer sizes (200–4000 m).

Existing literature has proposed three potential causes why socially disadvantaged populations may derive greater benefits from greenspace exposure (R. Mitchell and Popham, 2008; Rigolon et al., 2021; R. Wang et al., 2022). 1) People in disadvantaged groups are more likely to live in areas with poor environments, e.g., higher air and noise pollution (Bolte et al., 2010; Su et al., 2011). 2) Individuals with lower SES have limited mobility and typically spend more time close to home (Markevych et al., 2017). 3) Compared to individuals with higher SES, low-SES individuals may have few additional resources beyond greenspaces to enhance their health, e.g., fitness facilities and mental health counseling (R. Wang et al., 2022). Therefore, lower SES populations may rely more on neighborhood freely accessible greenspaces, thereby receiving a disproportionately high benefit from these greenspaces.

4.1.3. Inconsistent results by different greenspace measurements

We found discrepancies in the results introduced by different greenspace measurements, which suggested that the inconsistencies observed in previous greenspace-health studies may partly be attributed to different greenspace measurements used.

First, the equigenesis hypothesis is insignificant in the aggregate measurement but significant in all individual measurements. Ecological fallacy may cause such inconsistent results. In detail, using aggregate-level data to infer individual-level relationships may lead to ecological fallacy because it neglects the heterogeneity of data within groups (Freedman, 1999; Piantadosi et al., 1988). This finding aligns with existing research where the equigenic effect of greenspace on mental health has been observed through individual-level analysis (R. Wang et al., 2022), whereas the evidence supporting the equigenesis hypothesis of greenspace exposure and life expectancy is limited in aggregate-level analysis (Moran et al., 2021).

In addition, we found that the effects of greenspaces on life expectancy and equigenesis are both higher when measured by street-network buffer than by straight-line buffer, highlighting that using straight-line buffer as the individual measurement may underestimate the effects of greenspaces. The result supports prior research that using street-network analysis to generate an individual neighborhood can yield more nuanced representations of an individual's surrounding environment (Droin et al., 2023). The street-network buffer considers the actual accessibility and provides more accurate reflections of the real world than the straight-line buffer. Thus, we recommend further greenspace-health studies should use street-network buffer when data is available.

4.1.4. Optimal buffer distance of greenspace exposure

This study identified the effects of greenspaces across different buffer distances. Observations showed greenspace exposure is significantly related to life expectancy and equigenesis in all buffers from 200 m to 4000 m, demonstrating the robustness of the effects of greenspaces. Moreover, greenspace had the highest effect on life expectancy and equigenesis with the street-network buffer of 3000 m and 2500 m, respectively.

The observed higher effect for a larger buffer could be attributed to the multiple benefits of large-area greenspaces. Larger buffers have larger greenspace exposure, as our results showed: the mean (SD) NDVI of 200-m street-network buffer is 0.164 (0.088) and 0.183 (0.088) for 3000-m buffer. These greenspaces in a larger buffer may provide more benefits. These benefits include biodiversity enhancement, improved air quality, mitigation of heat exposure, and noise reduction (Hartig et al., 2014). These environmental improvements could reduce the risk of respiratory diseases, allergies, and cardiovascular problems (Markevych et al., 2017). Moreover, larger greenspaces provide higher recreational opportunities, which are associated with reductions in stress, obesity, and mental health disorders (Lu et al., 2018). Such cumulative benefits of large-area greenspace exposure may result in greater health benefits and overall well-being than greenspaces within smaller buffer zones.

4.2. Implication

This research holds several implications for researchers and professionals involved in urban planning and policy decisions. First, assessing the association between greenspace exposure and life expectancy aids in comprehending the potential improvements in life expectancy while considering exposure-related factors. It can contribute to the allocation and development of planning policy and resource deployment exposure. Given the significant effects of greenspace exposure on life expectancy among elderly individuals, especially those with lower socioeconomic status, intervention priority should be given to the creation and improvement of neighborhood greenspace in low SES areas. Second, we found inconsistent results among different greenspace measurements. Thus, greenspace-health studies should use individual-level data rather than aggregate-level data if feasible because the latter may lead to the ecological fallacy. Moreover, since straight-line buffers may underestimate the greenspace effect on life expectancy and equigenesis, researchers should use street-network buffers when measuring individual greenspace exposure. Third, when managing and designing for a healthy and age-friendly society, policymakers and urban designers should increase greenspace exposure within 3 km of residential neighborhoods, nursing homes, or other places with a high concentration of elderly population. This is because greenspace exposure within 2500–3000 m buffer distance had the most pronounced impact on improving life expectancy and reducing SES disparities of elderly individuals.

4.3. Limitations and opportunities for future research

Our research is subject to several limitations. First, because the individual or household income data were unavailable, we followed previous studies and used education level as a proxy to estimate the SES of the elderly population (Aikens and Barbarin, 2008; J. Liu et al., 2020; Moran et al., 2021). Using education as a proxy is considered feasible in this study because SES and education in China are significantly correlated, with a particularly strong association observed in first-tier cities (e.g., Guangzhou) (Liu et al., 2020). Nevertheless, further studies should also obtain individual/household income data when feasible. In addition, due to data unavailability, we did not control for a few factors that may affect life expectancy, including heat exposure, chronic disease, obesity, or smoking habits. Future research should validate our findings when the above individual data are available. Furthermore, this study only examined the effect of overall greenspaces via NDVI on life expectancy. We did not further investigate the differences in the effects of different greenspace types (e.g., forests, parks, grasslands) or other natural environmental factors (e.g., blue spaces). Future research should further investigate such effects to provide a more nuanced examination of the influence of natural environments on life expectancy. Moreover, while our valuable individual-level data allowed for a comprehensive analysis of the relationship between life expectancy and greenspace exposure in China at the citywide individual level, our study is constrained by the nature of the cross-sectional dataset. We cannot provide evidence for causality. Thus, well-controlled interventions or quasi-experimental research are warranted in future studies.

5. Conclusion

Our research comprehensively investigated the effects of greenspace exposure on life expectancy and equigenesis among elderly individuals in Guangzhou, China. We found that greenspace exposure may positively affect the life expectancy of the elderly population in China. Furthermore, the greenspace effect is stronger for elderly individuals with lower SES. Our study also identified optimal buffer distances for the direct and equigenic effects of greenspaces. Our findings emphasize the use of standardized and multiple greenspace measures across different studies. Overall, our research highlights the potential health benefits of greenspace, particularly for socially disadvantaged groups vulnerable.

Declaration of competing interest

The authors declare that they have no competing interests.

Data availability

The mortality data that has been used is confidential; other data will be made available on request.

Acknowledgment

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.healthplace.2023.103142.

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