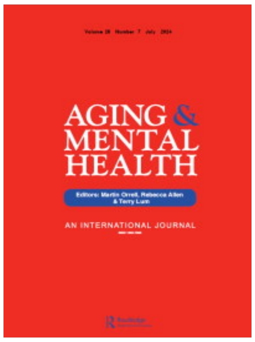


Aging & Mental Health

ISSN: (Print) (Online) Journal homepage: www.tandfonline.com/journals/camh20

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**To cite this article:** Ruoyu Wang & Yao Yao (28 Jun 2024): Exploring the pathways linking visual green space to depression in older adults in Shanghai, China: using street view data, Aging & Mental Health, DOI: 10.1080/13607863.2024.2363370

**To link to this article:** https://doi.org/10.1080/13607863.2024.2363370

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AGING & MENTAL HEALTH
https://doi.org/10.1080/13607863.2024.2363370

# Exploring the pathways linking visual green space to depression in older adults in Shanghai, China: using street view data

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**ABSTRACT**

**Objectives:** To examine (1) how visual green space quantity and quality affect depression among older adults; (2) whether and how the links may be mediated by perceived stress, physical activity, neighbourhood social cohesion, and air pollution ($PM_{2.5}$); and (3) whether there are differences in the mediation across visual green space quantity and quality.
**Method:** We used older adults samples (aged over 65) from the WHO Study on Global Ageing and Adult Health in Shanghai, China. Depression was quantified by two self-reported questions related to the diagnosis of depression and medications or other treatments for depression. Visual green space quantity and quality were calculated using street view images and machine learning methods (street view green space = SVG). Mediators included perceived stress, social cohesion, physical activity, and $PM_{2.5}$. Multilevel logistic and linear regression models were applied to understand the mediating roles of the above mediators in the link between visual green space quantity and quality and depression in older adults.
**Results:** SVG quantity and quality were negatively related to depression. Significant partial mediators for SVG quality were social cohesion and perceived stress. For SVG quantity, there was no evidence that any of the above mediators mediated the association.
**Conclusion:** Our results indicated that visual green space quantity and quality may be related to depression in older adults through different mechanisms.

**ARTICLE HISTORY**
Received 1 January 2024
Accepted 28 May 2024

**KEYWORDS**
Visual green space; depression; older adults; pathways; street view data

## Introduction

Healthy ageing has become an important issue in China, with 254 million ageing population aged over 60 years in 2019, which is approximately 18% of the total Chinese population (Lancet, 2022); this is estimated to reach 28% by 2040 (Y. Wu & Dang, 2013). The prevalence rate for depression among older Chinese (aged over 65) individuals was approximately 36.62% in 2015 (C. Jiang et al., 2020). Depression is the third leading disease contributing to disability worldwide (Vos et al., 2016) and is also linked to a higher risk of cancers (Pinquart & Duberstein, 2010) and mortality (Chan et al., 2023; Gilman et al., 2017), and lower quality of life (Sivertsen et al., 2015). Therefore, targeting depression in Chinese older adults is important for improving healthy ageing.

Green space can act as a nature-based solution contributing to health (Wang et al., 2020), so increasing attention has been given to the link between green space and depression (Gibney et al., 2020; Huang et al., 2021; Liu et al., 2023). Multiple cross-sectional (Di et al., 2020; Gascon et al., 2018) and longitudinal (Gonzales-Inca et al., 2022; R. Zhou et al. 2022) studies have reported negative relationships between green space and depression. For example, Gonzales-Inca et al. (2022) found that a low depression risk was related to more residential green space in a Finnish population cohort. Di et al. (2020) suggested that residential green space was negatively linked to anxiety and depression in China. Gascon et al. (2018) indicated that accessibility of green space was negatively related to the odds of reporting depression in Barcelona, Spain.

From the perspective of environmental gerontology (Figure 1), a neighbourhood environment such as green space can influence healthy ageing through health-related behaviour (Geller & Zenick, 2005; Sánchez-González & Egea-Jiménez, 2021). Environmental epidemiology and psychology reviews have identified several pathways linking green space to mental health, including reducing environmental hazards and building and restoring capacities (Markevych et al., 2017), which can also explain the association between green space and depression in older adults (Wu et al. 2015). The first pathway (Figure 1) concerns the mitigation of environmental stressors (reducing harms), which are usually related to poorer mental health (Wang et al., 2020; Xie et al. 2023). Green space such as urban trees can block traffic-related air pollutants and thus result in lower levels of air pollution (Tallis et al., 2011). For example, Wang et al. (2020) found that higher street-level vegetation was associated with better mental health through the mitigation effect of air pollution in Guangzhou, China. The second pathway (Figure 1) linking green space to mental health is the restorative impact of natural elements (restoring capacities) (Kaplan, 1995; Ulrich et al., 1991). This pathway highlights the impact of green space in buffering stress (Markevych et al., 2017). Stress Recovery Theory (SRT) suggests that people are unconsciously in favour of natural elements (e.g. vegetation) and have lower levels of stress in nature since

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Supplemental data for this article can be accessed online at https://doi.org/10.1080/13607863.2024.2363370.
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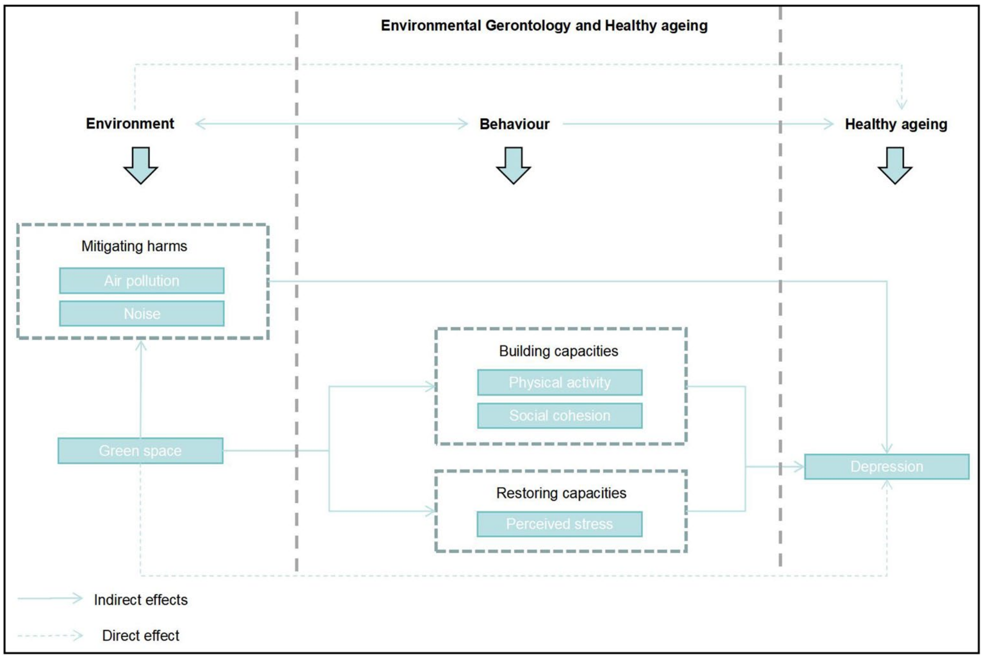


**Figure 1.** A conceptual framework linking green space to depression in later life from an environmental gerontology perspective.

human beings have benefited a lot from vegetation during the evolution process (Ulrich et al., 1991). Attention Restoration Theory (ART) points out that vegetation has four types of restorative features (i.e. being away, extension, compatibility and fascination), which can relieve people's stress (Kaplan, 1995). For instance, Dzhambov et al. (2019) suggested that green space was associated with lower depression by increasing mindfulness and resilience to stress and decreasing rumination in Plovdiv, Bulgaria. The last set of pathways (Figure 1) suggests that green space may contribute to building capacities for mental health, and relevant studies are primarily on the impacts of green space in increasing physical activity and neighbourhood social cohesion (Gascon et al., 2018). Green space contributes to more physical activity and social cohesion since it can provide people with a comfortable place for people to take outdoor physical activity and have social contact with neighbours (Wang et al., 2021). A study in US cities indicated that green space was linked to better mental health by encouraging more physical activity in older adults (Pun et al., 2018).

Numerous experiments have documented that visual exposure to green space is crucial, especially from a psychological perspective (Hedblom et al., 2019; Xiang et al. 2022). This is because green space has to be viewed first so that its restorative features can have an influence on relieving stress (Hedblom et al., 2019; Xiang et al. 2022). Nevertheless, evidence on the impact of visual green space on depression is scarce, while most of the existing studies still mainly shed light on using remote sensing data to measure green space quantity, and only used normalised difference vegetation index (NDVI) as an exposure metric (Wang et al., 2021). Remote sensing data reflects people's exposure to green space from a god-view perspective, which may overestimate green space since remote sensing-based metrics take into account all green space including the inaccessible and invisible ones (Wang et al., 2021). Visual exposure to green space reflects people's exposure to green space from a more human-view perspective and thus may be more related to mental health (Wang et al., 2021). For example, Helbich et al. (2019) found that visual exposure to green space was associated with less depression in older adults, while such finding was found for remote sensing-based green space. The ignorance of visual exposure to green space metrics is mainly due to technical limitations. Previous studies that assessed the impact of visual green space exposure were mainly experiments rather than observational studies since the current methods (e.g. filed audit) for assessing people's visual exposure to green space within a city are expensive and time-consuming (Markevych et al., 2017). Recently, street view data have attracted great attention regarding their potential to assess people's visual exposure to green space efficiently on a large scale (Kang et al., 2020). For instance, Wang et al. (2021) used street view data and a machine learning approach to assess people's exposure to green space and found that it was positively related to mental wellbeing in Guangzhou, China.

We have acknowledged several research gaps based on the above review. First, previous studies have mainly investigated the impact of green space based on remotely sensed green space measures, while few studies have focused on the impact of visual green space. Second, existing literature has only shed light on the pathways linking green space quantity to mental health, and it is still unclear how the quality aspect of green space matters due to technical limitations. Green space quantity refers to the objective volume of green space elements (i.e. vegetation), while green space quality reflects people's subjective perceptions of green space (Wang et al., 2021). Green space quality has received less attention than green space quantity since the traditional method (i.e. field audit) for assessing is inefficient (Wang et al., 2021). Nevertheless, in recent years, researchers have found that street view data along with a machine learning approach can be used to measure people's perception of the urban environment, and thus can be further used for evaluating green space quality (Wang et al., 2021). Additionally, existing evidence is mainly based on the general population, and there are not enough studies on the ageing population. Existing studies have suggested that older adults have lower daily mobility and may spend more time within residential neighbourhoods than younger adults due to more functional limitations, so they are more influenced by the residential neighbourhood environment (Shigematsu et al., 2009). Hence, there is evidence that older adults value green space more than young adults, which also makes green space crucial to them (Sang et al., 2016). Therefore, using a representative older population sample in Shanghai, China, we aim to understand (1) how visual green space quantity and quality affect depression among older adults; (2) whether and how the relationships may be mediated by perceived stress, social cohesion, physical activity, and $PM_{2.5}$; and (3) whether there are differences in the mediation across visual green space quantity and quality.

## Data and variables

### *WHO study on global ageing and adult health (SAGE) in Shanghai, China*

This study was based on the 2010 SAGE in Shanghai, China. The research team used a multistage random cluster sampling method to select a sample of respondents aged above 50 years in Shanghai. Based on the extraction probability (determined by the size of the population and area), neighbourhoods within each of the streets/townships were selected. As for the sampled neighbourhoods, a random selection of households was made, and all inhabitants aged 50 or more from the chosen households were part of the individual sample. The 'Kish grid' sampling technique was employed to divide the chosen households based on the number of people in the family to ensure that all households had an equal chance of being sampled at this stage. The participants included 9524 residents from 40 neighbourhoods (*juweihui*) in the five districts (Luwan, Hongkoui, Qingpu, Minhang and Nanhui). After eliminating those with incomplete data and below 65 years, we had a viable sample size of 2969 respondents. More details of the dataset can be found in F. Wu et al. (2015). WHO-SAGE China study got ethical approval from the Ethics Review Committee, World Health Organization, Geneva, Switzerland and the Ethics Committee, Shanghai Municipal Centre for Disease Control and Prevention, Shanghai, China.

### *Depression*

Depression was assessed based on two self-reported questions. SAGE participants were asked 'Have you ever been diagnosed with depression?' and 'Have you been taking any medications or other treatment for depression (other treatment can include attending therapy or counselling sessions)?'. Responses to the questions were either '0 = no' or '1 = yes'. Respondents who answered '1 = yes' to either of the above questions were treated as having depression.

### *Visual green space quantity and quality*

This study used street view images to quantify street view green space quantity (SVG quantity) and quality (SVG quality). We collected street view images from Tencent Map, which can provide mapping services for both commercial and academic purposes in China (Wang et al., 2021). Then we used the OpenStreetMap (Haklay & Weber, 2008) to construct sampling points (100-m intervals) for collecting the street view images. A total of 152956 images were created, and from each point of collection, four images were obtained at each of the sampling points (0, 90, 180 and 270 degrees). Based on prior research (Wang et al., 2022), we used ADE20K training data (B. Zhou et al. 2019) and a fully convolutional network (FCN-8s) (Yao et al. 2019) to calculate SVG quantity. This technique has been demonstrated to be successful in distinguishing green space from images with a high degree of precision (Wang et al., 2021). The SVG quantity for each street view image was calculated by the ratio of the number of green space pixels in each image. The SVG quantity in each neighbourhood was obtained by computing the mean SVG quantity for all street view images within a 1000-meter radius.

For SVG quality, we randomly chose 2000 images to build up the training database, which was assessed on a scale from 0 to 10 according to ten criteria, including naturalness, maintenance, absence of litter, safety, variation, colourfulness, accessibility, clear arrangement, general impression, and shelter (Cronbach's alpha > 0.80) (Wang et al., 2021). Then, we employed a random forest algorithm (Breiman, 2001) to teach the rating system, linking the 151 ground objects from the above segmentation process to the scores of each green space quality attribute. Once the random forest model was validated, it was utilized to assign scores to ten characteristics of green space quality for each of the 152956 images. Following Wang et al. (2021), the mean score of all ten attributes was used to measure the quality of green space in each image. The mean score of all images within a 1000-m buffer was used to determine the SVG quality for each neighbourhood.

### *Mediators*

Four potential mediators were included, as recommended in the previous studies (Markevych et al., 2017). First, physical activity (PA) was measured by their self-reported weekly moderate-intensity and vigorous-intensity PA time in minutes. The Global Physical Activity Questionnaire (GPAQ) has been validated in Chinese older adults (Bull et al., 2009). Second, social cohesion was assessed by nine 5-level items (Table S1), and we calculated the mean scores of these items (Cronbach's alpha > 0.85). The higher the scores, the higher the level of social cohesion a respondent had. This social cohesion scale has also been validated in Chinese older adults (Lee et al., 2020). Third, the 2-item version of the Perceived Stress Scale (Roberti et al., 2006) was applied to quantify respondents' perceived stress (Table S2). The Perceived Stress Scale has been validated in Chinese older adults (Huang et al., 2020). We calculated the mean scores of these items. The higher the scores, the higher the level of perceived stress a respondent had. Finally, we acquired the 2010 Global Annual $PM_{2.5}$ (Particulate Matter) data from NASA SEDAC with a resolution of 1 kilometre by 1 kilometre (van Donkelaar et al., 2016). We determined the yearly mean $PM_{2.5}$ level (μg/m$^3$) by averaging the pixel values within a 1000-m radius of the centre of each study area for the year 2010.

### *Covariates*

Following previous studies (Markevych et al., 2017), we controlled for a series of individual covariates: sex, age, educational attainment, marital status, annual household income per capita (Chinese Yuan), employment status, smoking and drinking status. Functional limitations were assessed based on a 22-item questionnaire (Table S3), which aimed to understand the difficulties respondents had in performing a series of daily activities. As most of the respondents answered 'None' to all questions, we treated the functional limitation as a binary variable (functionally limited = others, not functionally limited = those who answered 'None' to all questions).

For neighbourhood-level covariates, we adjusted for urbanity, population density (people/km$^2$), connectivity of interactions (numbers/km$^2$) and mixed land use (0–1) following Frank et al. (2006). We also calculated the distance to the nearest park (m) to control for the influence of large green infrastructures. Finally, we included the neighbourhood deprivation index (NDI) as a proxy for measuring neighbourhood-level socioeconomic status. Following Sampson et al. (2002) and Wang et al. (2022), we used four census indicators (low levels of education rates, unemployment rates, home-ownership rates, and low-status occupations rates) in Shanghai to calculate NDI. Then, we used a principal component analysis to synthesize the NDI. The higher the NDI, the more deprived a neighbourhood was. A summary of the descriptive statistics is shown in Table 1.

**Table 1.** Statistical summary of the variables.

| Variables | Mean value (SD)/ proportion |
|---|---|
| Outcome | |
| Diagnosis of depression | |
| Yes | 0.01 |
| No | 0.99 |
| Predictors | |
| SVG quantity (0–1) | 0.19(0.10) |
| SVG quality (0–1) | 0.62(0.08) |
| Mediators | |
| Weekly PA (mins) | 192.67(445.34) |
| Social cohesion (1–5) | 1.55(0.40) |
| Perceived stress (2–10) | 4.01(1.50) |
| $PM_{2.5}$ (μg/m$^3$) | 54.76(4.04) |
| Covariates | |
| Place of residence | |
| Urban area | 0.51 |
| Rural area | 0.49 |
| Sex | |
| Male | 0.47 |
| Female | 0.53 |
| Age | |
| <70 years | 0.49 |
| 70–79 years | 0.51 |
| >=80 years | 0.19 |
| Marital status | |
| Married | 0.74 |
| Others | 0.26 |
| Educational attainment | |
| ≤Primary school | 0.67 |
| High school | 0.25 |
| ≥College | 0.08 |
| Annual household income per capita (Chinese Yuan) | 16869.91(59675.50) |
| Employment status | |
| Employed | 0.89 |
| Others | 0.11 |
| Functional limitations | |
| Yes | 0.12 |
| No | 0.88 |
| Smoking | |
| Yes | 0.23 |
| No | 0.77 |
| Drinking | |
| Yes | 0.16 |
| No | 0.84 |
| NDI | 0.50(1.75) |
| Neighbourhood population density (people/km$^2$) | 29244.96(37055.81) |
| Mixed land use (0–1) | 0.15(0.03) |
| Connectivity of interactions (numbers/km$^2$) | 40.58(39.09) |
| Distance to the nearest park (m) | 2377.46(3084.69) |

## Methods

### *Multilevel regression models*

To explore how the link between SVG and depression was explained by the mediators, including PA, social cohesion, perceived stress and $PM_{2.5}$, we followed a multistep mediation analysis procedure (Baron & Kenny, 1986). We fitted both multilevel logistic regression models and multilevel linear regression models (Gelman & Hill, 2006) with a random intercept for each neighbourhood. Variance inflation factors (VIFs < 3) were calculated and it suggested that there was no severe multicollinearity among predictors. First, we identified the relationship between SVG and participants' odds of reporting depression (Model 1). Second, in Models 2 to 5, we regressed each mediator on SVG (PA, social cohesion, perceived stress and $PM_{2.5}$) to understand how was SVG related to mediators. Third, Models 6 to 9 determined the association between SVG and participants' odds of reporting depression and included the mediators one at a time. Finally, we used the sparse compositional mediation model (Sohn et al., 2021) for depression (binary outcome) to test the significance of the mediation effects. We defined statistical significance as $p < 0.05$. Also, we stratified the analysis between people over 75 and below 75 to test whether the green space-depression association may vary across different age groups (Models S1 to S18). The analysis was conducted based on STATA 15.1 (StataCorp, College Station, TX, USA).

## Results

### *Correlations between SVG and depression*

Table 2 displays the results of the adjusted model for the link between SVG and depression. The results (Model 1) indicate that annual household income per capita was negatively related to respondents' odds of having depression (OR = 0.99; 95% CI = 0.99–0.99), while respondents with functional limitations were more likely to have depression (OR = 3.89; 95% CI = 1.46–10.32).

**Table 2.** Association between SVG and depression.

| | Model 1 OR (95% CI) |
|---|---|
| Urban neighborhood (reference group = rural neighborhood) | 0.48(0.05,5.05) |
| Male (reference group = female) | 0.67(0.21,2.10) |
| Age (reference group= < 70 years) | |
| 70–79 years | 1.89(0.65,5.52) |
| > = 80 years | 0.93(0.19,4.58) |
| Married (reference group = others) | 2.23(0.69,7.18) |
| Educational attainment (reference group = ≤primary school) | |
| High school | 1.71(0.49,6.00) |
| ≥College | 1.25(0.12,12.60) |
| Annual household income per capita | 0.99**(0.99,0.99) |
| Employed (reference group = others) | 1.84(0.61,5.61) |
| Functional limitations (reference group = no functional limitations) | 3.89**(1.46,10.32) |
| Smoker (reference group = nonsmoker) | 1.01(0.24,4.16) |
| Drinker (reference group = nondrinker) | 0.51(0.10,2.57) |
| Population density | 0.99(0.99,1.00) |
| NDI | 0.93(0.54,1.60) |
| Connectivity of interactions | 0.99(0.98,1.02) |
| Mixed land use | 0.01(0.00,218.17) |
| Distance to the nearest park | 0.99(0.99,1.00) |
| SVG quantity | 1.26(0.61,2.60) |
| SVG quality | 0.22***(0.07,0.70) |
| Log-likelihood | −118.24 |
| AIC | 276.48 |

OR = odds ratio; CI = confidence interval; AIC = Akaike information criterion. Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

Although SVG quality (OR = 0.22 95% CI = 0.07–0.70) was negatively associated with respondents' odds of having depression, there was no evidence that SVG quantity (OR = 1.26; 95% CI = 0.61–2.60) was also linked to respondents' odds of having depression.

### Correlations between SVG and potential mediators

Table 3 presents the correlations between SVG and potential mediators. Model 2 shows the association between SVG and PA. SVG quantity (Coef. = 74.39; SE = 13.91) was positively related to PA, but there was no evidence that SVG quality (Coef. = −40.75; SE = 22.53) was also related to PA. Model 3 presents the link between SVG and social cohesion. SVG quality was positively related to social cohesion (Coef. = 0.13; SE = 0.04), but there was no evidence that SVG quantity (Coef. = −0.04; SE = 0.03) was also linked to social cohesion. Model 4 displays the association between SVG and perceived stress. SVG quality was negatively related to perceived stress (Coef. = −0.18; SE = 0.05), but there was no evidence that SVG quantity (Coef. = 0.03; SE = 0.13) was also related to perceived stress. Model 5 shows the association between SVG and $PM_{2.5}$. SVG quality (Coef. = 1.22; SE = 0.12) was positively related to $PM_{2.5}$, but there was no evidence that SVG quantity (Coef. = −0.04; SE = 0.08) was also associated with $PM_{2.5}$.

### Correlations among mediators, SVG, and depression

Table 4 shows the results concerning how the relationships between SVG and depression were mediated, while Table 5 summarizes the direct and indirect effects through different mediators. Model 6 and the results in Table 5 suggest that there was no evidence that PA mediated the link between SVG quantity and depression or the link between SVG quality and depression. Model 7 and the results in Table 5 suggest that although social cohesion mediated the relationship between SVG quality and depression, there was no evidence that social cohesion mediated the association between SVG quantity and depression. Model 8 and the results in Table 5 show that perceived stress mediated the link between SVG quality and depression. However, there was no evidence that perceived stress was a mediator between SVG quantity and depression. Model 9 and the results in Table 5 suggest that there was no evidence that $PM_{2.5}$ mediated the association between SVG quantity and depression or between SVG quality and depression. The stratified analysis (Models S1 to S18) indicates that despite some

**Table 3.** Association between SVG and the mediators.

| | Model 2 (DV = PA) Coef. (SE) | Model 3 (DV = Social cohesion) Coef. (SE) | Model 4 (DV = Perceived stress) Coef. (SE) | Model 5 (DV = $PM_{2.5}$) Coef. (SE) |
|---|---|---|---|---|
| Urban neighborhood (reference group = rural neighborhood) | −6.86(20.42) | −0.06(0.06) | 0.13(0.24) | 5.52***(0.25) |
| Male (reference group = female) | 29.37(14.33) | −0.02(0.02) | −0.11*(0.06) | −0.15(0.14) |
| Age (reference group= < 70 years) | | | | |
| 70–79 years | −36.71*(18.93) | 0.00(0.02) | 0.18***(0.06) | 0.29**(0.13) |
| > = 80 years | −79.53***(25.75) | −0.05**(0.02) | 0.36***(0.08) | 0.11(0.17) |
| Married (reference group = others) | −23.95(19.81) | −0.00(0.02) | 0.09(0.06) | −0.03(0.13) |
| Educational attainment (reference group = ≤primary school) | | | | |
| High school | 9.88(21.74) | 0.09***(0.02) | −0.28***(0.07) | 0.17(0.14) |
| ≥College | 51.91(33.55) | 0.14***(0.02) | −0.38***(0.11) | 0.11(0.22) |
| Annual household income per capita | −0.00(0.00) | −0.00*(0.00) | −0.00(0.00) | 0.00(0.00) |
| Employed (reference group = others) | 15.96(27.12) | 0.07***(0.02) | −0.23***(0.09) | 0.72***(0.18) |
| Functional limitations (reference group = no functional limitations) | −105.01***(25.20) | −0.16***(0.02) | 0.77***(0.08) | −0.49***(0.11) |
| Smoker (reference group = nonsmoker) | −16.49(23.81) | 0.02(0.02) | 0.16***(0.07) | 0.44***(0.16) |
| Drinker (reference group = nondrinker) | 10.59(24.50) | 0.04**(0.02) | −0.12(0.08) | 0.10(0.16) |
| Population density | 0.00(0.00) | 0.00(0.00) | −0.00(0.00) | 0.00(0.00) |
| NDI | −21.40**(8.70) | −0.02(0.02) | 0.11(0.07) | 0.22***(0.05) |
| Connectivity of interactions | −0.18(0.45) | 0.00**(0.00) | −0.00(0.00) | 0.03***(0.00) |
| Mixed land use | −70.61(337.17) | 1.32**(0.63) | −3.90(3.05) | −3.78***(1.83) |
| Distance to the nearest park | −0.01(0.00) | 0.00(0.00) | 0.00(0.00) | 0.00***(0.00) |
| SVG quantity | 74.39***(13.91) | −0.04*(0.03) | 0.03(0.13) | −0.04(0.08) |
| SVG quality | −40.75*(22.53) | 0.13***(0.04) | −0.18***(0.05) | 1.22***(0.12) |
| Log-likelihood | −22207.79 | −1282.15 | −5058.94 | 14760.12 |
| AIC | 44459.59 | 2608.31 | 10161.89 | −7359.06 |

DV = dependent variable; Coef. = coefficient; SE = standard error; AIC = Akaike information criterion. Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

**Table 4.** Association between SVG and depression: the mediating effects of PA, social cohesion, perceived stress and $PM_{2.5}$.

| | Model 6 (Mediator = PA) OR (95% CI) | Model 7 (Mediator = Social cohesion) OR (95% CI) | Model 8 (Mediator = Perceived stress) OR (95% CI) | Model 9 (Mediator = $PM_{2.5}$) OR (95% CI) |
|---|---|---|---|---|
| SVG quantity | 1.30(0.64,2.68) | 1.26(0.61,2.60) | 1.12(0.56,2.26) | 1.26(0.61,2.61) |
| SVG quality | 0.22***(0.07,0.68) | 0.22**(0.07,0.70) | 0.20***(0.06,0.65) | 0.23**(0.07,0.70) |
| PA | 0.99(0.99,1.00) | | | |
| Social cohesion | | 0.94**(0.30,0.99) | | |
| Perceived stress | | | 1.81***(1.36,2.40) | |
| $PM_{2.5}$ | | | | 0.99(0.86,1.15) |
| Log-likelihood | −117.741 | −118.24 | −109.31 | −118.24 |
| AIC | 277.48 | 278.48 | 260.62 | 278.48 |

Al models were adjusted for covariates. OR = odds ratio; CI = confidence interval; AIC = Akaike information criterion. Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

**Table 5.** Indirect effects of the mediation analyses.

| IV | Mediator | Mediating effect (SE) | Direct effect (SE) |
|---|---|---|---|
| SVG quantity | PA | −0.071(0.089) | 0.266(0.367) |
| | Social cohesion | 0.002(0.001) | 0.233(0.369) |
| | Perceived stress | 0.018(0.077) | 0.114(0.358) |
| | $PM_{2.5}$ | 0.000(0.003) | 0.233(0.370) |
| SVG quality | PA | 0.039(0.053) | −1.519***(0.577) |
| | Social cohesion | −0.006**(0.003) | −1.496**(0.578) |
| | Perceived stress | −0.107***(0.039) | −1.614***(0.605) |
| | $PM_{2.5}$ | −0.005(0.091) | −1.491**(0.577) |

IV = independent variable; SE = standard error. Significance levels: *$p < 0.10$, **$p < 0.05$, ***$p < 0.01$.

differences in odds ratios or coefficients, the green space-depression associations remained the same across different age groups.

## Discussion

In this study, we systematically investigated the pathways linking visual green space quantity and quality to depression among older adults using street view images and a machine learning method. There are several contributions to be noted. First, we evaluated visual green space rather than remotely sensed green space measures. Second, we considered both visual green space quantity and quality measures, which are both important for mental well-being. Third, we shed light on depression in older adults, which may contribute to the field of environmental gerontology. Finally, based on the "environment – behaviour – healthy ageing" conceptual framework (Figure 1), we included multiple mediators that can provide a more comprehensive understanding of the mechanisms linking green space to depression, which further contributes to existing knowledge of environmental gerontology.

The results suggested that social cohesion and perceived stress may mediate the link between SVG quality and older adults' depression. Exiting literature from Western countries has also pointed out that neighbourhood green space is related to reduced levels of depression by improving neighbourhood social cohesion (de Vries et al., 2013; Liu et al., 2023; Sugiyama et al., 2008). However, this pathway has rarely been explored for the ageing population in China. The findings from this study confirm the assumption that green space may offer older adults a pleasing environment to contact with their neighbours (Hanibuchi et al., 2012; Hong et al., 2018; Jennings & Bamkole, 2019). In addition, previous studies have shown that older adults in socially cohesive neighbourhoods usually have better mental health since they can obtain more social support and health-related knowledge in such a neighbourhood (Cramm et al., 2013; Choi & Matz-Costa, 2018). Previous studies have mainly treated perceived stress as a direct outcome of green space exposure (B. Jiang et al., 2014), while only a handful of studies have explored the mediating effect of perceived stress in the relationship between green space and depression (Liu et al., 2023). Regarding the association between perceived stress, both stress reduction theory and attention restoration theory highlight the role of green space in mitigating the negative effect of psychological stress (Kaplan, 1995; Ulrich et al., 1991). The first theory indicates that viewing natural elements such as green space can provide people with a sense of safety and reduce stress since they were important resources for human ancestors during the evolution process (Ulrich et al., 1991), while the second one suggests that green space can facilitate the brain's ability to take a break from inhibitory processes, thus alleviating symptoms of attention fatigue (Kaplan, 1995). Hence, the accumulation of daily perceived stress is linked to a higher risk of depression since it can increase unhealthy coping, disrupt relationships, and further generate more serious stress (Hammen, 2015; Yang et al. 2015).

The results showed no evidence that green space in neighbourhoods prevents depression by increasing physical activity or mitigating $PM_{2.5}$, which contradicts previous findings (Gascon et al., 2018; Wang et al., 2021). There are several explanations for such a finding in the Chinese context. First, a higher level of vegetation quality does not necessarily imply a higher level of quantity or availability of green space, which can reflect the capability of green space to host users (Arnberger et al., 2017). When there is not enough green space, people are more likely to have a sense of crowdedness in green space, which may prevent them from taking more physical activity (Schipperijn et al., 2013). Second, we did not have older adults' physical activity information regarding its type and other details, so our sampled older adults may have been more willing to conduct indoor physical activity rather than physical activity in green space. Regarding the nonsignificant meditating effect of air pollution, one possible explanation is that there were limited variances in the level of $PM_{2.5}$ across the target neighbourhoods. The 40 sampled neighbourhoods for this study are mainly located in the inner rings of Shanghai city, so differences in $PM_{2.5}$ levels across these neighbourhoods could be relatively small, which may have reduced its statistical power in the mediation analysis.

However, whereas SVG quality was related to depression in older adults, no evidence was found to suggest that SVG quantity was also linked to depression. We must acknowledge that this study is not able to provide a conclusion that SVG quantity does not reduce depression. We have acknowledged several potential reasons why evidence for the link between SVG quantity and depression was not found in this research. First, a greater green space quantity may also be related to a lower level of safety perception, since green space can contribute to more crimes due to its potential function as a shield for gangs (Bogar & Beyer, 2016). Second, since previous studies have suggested that there may be a dose-response relationship between green space quantity and its restorative function (B. Jiang et al., 2014), it is possible that SVG quantity in our study area may not have been great enough to contribute to depression in older adults. Third, existing studies found that there are species of vegetation associated with allergic symptoms (Stas et al., 2021), so some vegetation in our research area may even be associated with unpleasant experiences for an ageing population. Last, we did not have mobility information for participants throughout the year, and their outdoor activities may be more intense in winter when the level of greenness is relatively low.

## Limitations

Despite the contributions of our study, it still has some limitations. First, since SAGE data is cross-sectional, we could not infer causality regarding the links among green space, mediators and depression. Second, although depression is based on diagnosis and medication information, it was still self-reported and may have lacked objective measurements in this study. Additionally, some mediators, such as physical activity and perceived stress, were based on self-reported questions and were incorporated through people's subjective experiences, so there is the possibility of measurement bias. Third, street view data are also not without limitations. For example, street view data were collected by cars, which may not be able to fully reflect pedestrians' perceptions of the environment on the street. Additionally, although the accuracy of FCN-8s is above 85% in identifying natural elements, it may have still led to bias in some areas where the quality of images is not sufficient. Fourth, despite our efforts in adjusting for key individual-level covariates, some covariates were likely to be missing (e.g. preference for the natural environment). Since we do not have relocation information on SAGE samples, residential self-selection bias remains an issue. Finally, we assessed green space exposure using a circular buffer for each neighbourhood, which may have resulted in the modifiable areal unit problem (Fotheringham & Wong, 1991).

## Conclusion

This national study focused on pathways between visual green space quantity and quality and depression in older adults. Our results provide evidence that both visual green space quantity and quality represent different aspects of natural environments. Our analysis showed that SVG quantity and SVG quality were negatively linked to depression among Chinese older adults. Additionally, social cohesion and perceived stress partially mediated the association between SVG quality and depression, while there was no evidence that any of the mediators contributed to the association. Overall, visual green space quantity and quality may contribute to depression in older adults using different mechanisms. Therefore, policy-makers need to improve the provision of both visual green space quantity and quality within cities.

## Disclosure statement

No potential conflict of interest was reported by the author(s).

## Funding

The study is supported by the National Key Research and Development Program of China [2019YFB2102903] and the Guangdong-Hong Kong-Macau Joint Laboratory Program [2020B1212030009].

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