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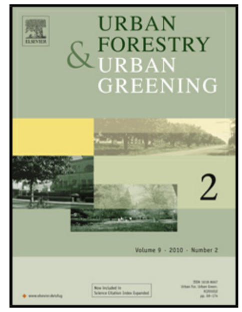

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Abstract
Recent decades have witnessed rapid urban expansion in China and the associated reduction in people's access to natural outdoor environments (NOE), but whether access to NOE increases people's subjective well-being (SWB) remains inconclusive in the high-density urban setting. This study aims to examine the association of access to NOE (green and blue spaces) with each component of SWB (life satisfaction, positive affect, and negative affect), using cross-sectional study data collected in 23 neighbourhoods in Guangzhou, China. It particularly focuses on how different measures of access to NOE (streetscape metrics derived from Tencent street-view data and satellite-derived metrics derived from land cover data) matter to relationships between NOE and SWB and the extent to which these relationships vary by individual socioeconomic status. Results from seemingly unrelated regressions (SURs) show that green view index and the amount of surrounding greenness are related to a lower level of negative affect, and blue view index and the amount of surrounding blueness are associated with more satisfaction with life. The amount of surrounding blueness is linked to a higher level of positive affect. Results from stratified analyses indicate that NOE-SWB associations are heterogeneous depending on individuals' housing tenure, educational attainment, household registration status, and income. Our findings demonstrate that streetscape metrics and satellite-derived metrics capture different aspects of access to NOE, which are related to different components of SWB.

Keywords: subjective well-being; natural outdoor environments; street view imagery; remote sensing imagery; China

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Highlights

- We examine the relationship between access to natural outdoor environments and subjective well-being.
- Streetscape and satellite-derived access metrics capture different aspects of natural outdoor environments.
- Different metrics of access to natural outdoor environments are related to different components of subjective well-being.

Abstract

Recent decades have witnessed rapid urban expansion in China and an associated reduction in people's access to natural outdoor environments (NOE), but whether access to NOE increases people's subjective well-being (SWB) remains inconclusive in the high-density urban setting.

This study aims to examine the association of access to NOE (green and blue spaces) with each component of SWB (life satisfaction, positive affect, and negative affect), using cross-sectional study data collected in 23 neighbourhoods in Guangzhou, China. It particularly focuses on how different measures of access to NOE (streetscape metrics derived from Tencent street-view data and satellite-derived metrics derived from land cover data) matter to relationships between NOE and SWB and the extent to which these relationships vary by individual socioeconomic status. Results from seemingly unrelated regressions (SURs) show that green view index and the amount of surrounding greenness are related to a lower level of negative affect, and blue view index and the amount of surrounding blueness are associated with more satisfaction with life. The amount of surrounding blueness is linked to a higher level of positive affect. Results from stratified analyses indicate that NOE-SWB associations are heterogeneous depending on individuals' housing tenure, educational attainment, household registration status, and income. Our findings demonstrate that streetscape metrics and satellite-derived metrics capture different aspects of access to NOE, which are related to different components of SWB.

Keywords: subjective well-being; natural outdoor environments; street view imagery; remote sensing imagery; China

1. Introduction

The 2018 Revision of the World Urbanization Prospects reported that nearly 60% of the total population in China lived in urban areas (UN, 2019). It is forecast that Chinese cities will absorb over 190 million from the rural population between 2018 and 2030 (UN, 2019). Such rapid urbanization has considerably reduced people's chance of accessing natural outdoor environments (hereafter NOE, including green and blue spaces in the current study) by converting massive areas of forests, woodland, pasture, and cropland into urban areas (Chen et al., 2010; Gu, 2019). Although China's real GDP per capita has increased tenfold over the past three decades, the level of individual life satisfaction and happiness among its nationals remains stagnant (Easterlin et al., 2012, 2017). Environmental degradation and the loss of ecosystem services have been officially considered to represent great threats to Chinese people's wellbeing in recent years, and China's government has highlighted the role of environmental protection and sustainable development (called 'ecological civilization') in improving people's wellbeing (Xi, 2017). Despite the surge in governmental attention, evidence on the salutogenic effect of contacting with NOE, especially blue spaces, in the Chinese context is limited. Quantifying the relationship between contact with NOE and SWB can contribute to better policy and practices in land use planning, for example by providing a minimum standard guideline for the provision of green/blue spaces in land use zoning.

While evidence is mounting that access to NOE is associated with a higher level of SWB in Western countries (Brereton et al., 2008; Dadvand et al., 2019; Fleming et al., 2016; Mackerron and Mourato, 2013; Mavoa et al., 2019a; White et al., 2013a, 2017), it is only recently that researchers have investigated the linkage between access to urban green spaces and SWB, or the cognitive component of SWB, namely life satisfaction, in Chinese large cities (Dong and Qin, 2017; Liu et al., 2017; Ma et al., 2018; Wu et al., 2019a, 2019b). Far less attention has been paid to the association between access to urban blue spaces and residents' SWB in China, although some studies carried out in developed countries have suggested that living near aquatic environments, interacting with blue spaces or viewing natural waterscapes may lower psychological distress and improve pro-environmental behaviour, affective restoration, life satisfaction, self-perceived general health, and mental health (Brereton et al., 2008; Hooyberg et al., 2020; Nutsford et al., 2016; Pasanen et al., 2019; van den Berg et al., 2003; Völker and Kistemann, 2011, 2015; Wheeler et al., 2012; White et al., 2013a). Nevertheless, other studies have found no evidence in support of the beneficial impacts of blue spaces on health and wellbeing (Gascon et al., 2018; Triguero-Mas et al., 2015; White et al., 2013a). It is worthwhile to examine the dose-effect relationship between NOE and SWB in the Chinese high-density urban context, as people's opportunity, motivation, and ability to use green/blue spaces in China may be different from their counterparts in Western countries (Chen and Wang, 2013; Jim and Shan, 2013; Xiao et al., 2017; Wu et al., 2019b). Chinese people residing in urban areas may have fewer opportunities to use green/blue spaces in their residential neighbourhoods due to rapid urban sprawl and the decreasing amount of NOE (Xiao et al., 2017), compared with their counterparts in Western countries. Therefore, the NOE-SWB associations may differ between the Chinese context and the Western context.

While the majority of earlier studies conducted in Europe, North America and East Asia have explored the linkage between access to NOE and life satisfaction (i.e. the cognitive component of SWB) (for example, Bertram and Rehdanz, 2015; Brereton et al., 2008; White et al., 2013a, 2017; Ma et al., 2018; Wu et al., 2019a), much less attention has been paid to affectivity (the affective component of SWB) and its relation with NOE (for example, Anderson et al., 2018; Berman et al., 2012; Bratman et al., 2015; Kondo et al., 2019; Liu et al., 2016, 2017). Only a handful of studies have taken into account both cognitive and affective components of SWB when examining their associations with neighbourhood built environments and social environments (Liu et al., 2016, 2017; White et al., 2017; Zhang and Zhang, 2017). However, most of these studies tend to run OLS regressions separately for different components of SWB. Such an equation-by-equation approach would cause the problem of insufficient estimates, as each equation contained exactly the same set of variables on the right hand side, and the error term of equations is statistically correlated (Brenner, 1975; Diener, 1984; Kammann et al., 1979). This would require the use of seemingly unrelated regressions (SURs) instead of equation-by-equation OLS regressions to generate more efficient estimates of coefficients.

This paper aims to investigate the association between access to NOE and SWB using a population sample of 1,150 residents living in 23 residential neighbourhoods in Guangzhou, a metropolitan city in South China. It advances previous work on the therapeutic effect of NOE on SWB in the following respects. First, it explores whether access to surrounding blue spaces plays a role in different components of SWB in the Chinese high-density urban context. Second, it goes beyond earlier studies by using the SUR technique to efficiently estimate the linkage between NOE and SWB. Practically, this study will provide guidelines for urban planners and landscape architects to enable residents to access NOE in the city.

2. Literature review

SWB refers to individuals' cognitive and affective evaluation of life, including both cognitive judgement of life satisfaction and emotional reactions to life events (Diener, 1984). SWB differs from mental wellbeing, as mental wellbeing represents a good performance of mental function, which results in productive activities, fulfilling relationships with others, and the ability to adapt to change and deal with adversity (Satcher, 2000). Accumulated epidemiological evidence is suggestive of a range of health and wellbeing benefits from contact with NOE, including improvement in cardiovascular functions, higher levels of physical activities, lower risk of psychiatric disorders, reduction in stress and anxiety, and lower risk of overweight/obesity (de Vries et al., 2013; Engemann et al., 2019; Fan et al., 2011; Gascon et al., 2018; Helbich et al., 2019; Lachowycz and Jones, 2011; Richardson et al., 2013; Xie et al., 2021).

Previous studies have indicated several potential pathways linking access to green spaces to the alleviation of mental illness: mitigating environmental stressors (e.g., air pollution, noise and extreme temperature), encouraging physical exercise, enhancing social contact and social support among neighbours, reducing stress, and restoring attention capacity (Gascon et al., 2015; Hartig et al., 2014; Lachowycz and Jones, 2013; Markevych et al., 2017; Nieuwenhuijsen et al., 2017). Several observational studies carried out in China confirmed the existence of the above biopsychosocial pathways through which access to green spaces alleviated depressive symptoms and improved mental wellbeing (Liu et al., 2019a, 2019b, 2020; Wang et al., 2019a). Other studies found that residential green spaces buffered the adverse effect of environmental hazards (e.g., noise and air pollution) on mental health, as vegetation not only directly caused a physical reduction in noise and air pollutants but also aroused feelings of calm (Dzhambov et al., 2018a, 2018b). Studies in European and North American countries further suggested that physical activities performed in green spaces might generate greater mental benefits compared with those in other settings (Mitchell, 2013; Mytton et al., 2012; Thompson Coon et al., 2011). A psychological explanation for the beneficial effect of interacting with nature is that viewing vegetation can restore attention capacity and thereby alleviate the symptoms of rumination and negative moods (Berman et al., 2012; Kaplan, 1995). For the current study, we hypothesize that access to green spaces is positively associated with higher SWB.

While a growing body of literature has attempted to explore the potential role of access to green spaces in promoting SWB (Bertram and Rehdanz, 2015; Dong and Qin, 2017; Liu et al., 2017; Ma et al., 2018; White et al., 2017), surprisingly little research has been done on the linkage between access to blue spaces and SWB. A handful of studies have investigated the link between access to aquatic environments (e.g., coastlines, lakes, rivers) and SWB in developed countries, generating inconsistent results (Brereton et al., 2008; Nutsford et al., 2016; White et al., 2013a). For example, a cross-sectional study of the Irish population showed that residential proximity to the coast was positively associated with life satisfaction (Brereton et al., 2008). Similarly, another cross-sectional study conducted in Hong Kong among older adults indicated that those who had contact with blue spaces on a regular basis reported better SWB than those who did not (Garrett et al., 2019). However, a study based on English panel data showed no evidence that residential proximity to the coast influenced life satisfaction (White et al., 2013a). Several pathways linking access to blue spaces and life satisfaction can be identified (Gascon et al., 2018; Grellier et al., 2017; Triguero-Mas et al., 2015). First, water bodies can contribute to the mitigation of extreme heat and road traffic noise, thereby increasing residents' satisfaction with life (Jeon et al., 2010; Völker et al., 2013). Second, people living near the coast, lakes, and rivers are more likely to engage in physical activities, as coastlines, lake shores, and riverbanks serve as pleasant and accessible places to be physically active (Bauman et al., 1999; White et al., 2014). Third, coastlines, lake shores, and riverbanks provide a favourable setting for people to socialise with their family and friends (Ashbullby et al., 2013). Fourth, exposure to water bodies exerts positive effects on wellbeing through evoking awe (Anderson et al., 2018). Fifth, blue spaces with different objective and perceived environmental conditions (i.e., climate, temperature, air quality, water and tide) have an influence on the level of perceived psychological restorativeness (Hipp and Ogunseitan, 2011). Both doing physical activity and interacting with family and friends can contribute to an increase in life satisfaction. In addition, families living near to the coast and rivers generally have higher income and more ability to pay than those living further away, and the former group tends to be more satisfied with life than the latter group (Völker and Kistemann, 2015). Therefore, we hypothesize an association between access to blue spaces and higher SWB among Chinese urban residents.

Previous studies have indicated that the linkage between NOE and wellbeing is moderated by numerous factors, including the demographic attributes of users, the characteristics of green/blue spaces, the socioeconomic environment and climatic conditions (Avolio et al., 2014, 2015; Lachowycz and Jones, 2013). These potential moderators play a role in shaping the opportunity to use green/blue spaces, the ease and personal motivation to do so, and the preferences and perceptions of such spaces (Avolio et al., 2014, 2015; Lachowycz and Jones, 2013). Specifically, observational evidence has suggested that the NOE-wellbeing relationship varies by gender, age, income, education level and urbanicity, and is not consistent across the life course (Astell-Burt et al., 2014; Kondo et al., 2019; Liu et al., 2019b; Maas et al., 2006, 2009; Sarkar et al., 2018; Triguero-Mas et al., 2015; Wheeler et al., 2012). However, there is no consensus on the extent to which access to NOE was linked to health outcomes. Considering the growing disparity between the rich and the poor and between migrants and local residents in Chinese cities, which may lead to differences in their opportunity to access NOE, we shed light on the moderating role of socioeconomic status in the linkage between NOE and SWB.

Technically, most prior studies have measured individuals' access to NOE using either metrics derived from remote sensing data or land use/land cover maps (Dadvand et al., 2019; Dong and Qin, 2017; Fleming et al., 2016; Ma et al., 2018; Mackerron and Mourato, 2013; White et al., 2013a, 2017). However, these metrics are based on a bird's eye view and thereby fail to assess people's perception of their surrounding environment on the ground (Helbich et al., 2019; Ye et al., 2019). Another problem with these metrics is the inaccuracy of measuring the level of greenery. For example, remote sensing data and land use/land cover maps may not be able to capture small vegetation (e.g. trees along driveways), which is important for people's exposure to greenery in daily life. A few studies have used either trained auditors' field observations or respondents' self-reports to measure the quantity and quality of green spaces (Avolio et al., 2014, 2015; Fleming et al., 2016; Kondo et al., 2019; Sugiyama et al., 2008). Nevertheless, these manual auditing approaches are subjective, laborious, and time-consuming. Recent years have witnessed a rise in interest in using street view data and deep learning techniques to automatically assess people's exposure to green spaces within their residential neighbourhood (Rzotkiewicz et al., 2018; Brindley et al., 2019; Helbich et al., 2019; Lu, 2018, 2019; Wang et al., 2019a; Ye et al., 2019), but attempts to use the same technique to assess people's exposure to blue spaces are rather rare (Helbich et al., 2019; Liu et al., 2020).

Another technical limitation of prior research on multiple components of SWB is related to contemporaneous cross-equation error correlation across equations. When estimating the NOE-SWB relationship, previous studies have separately estimated the relationship between NOE and each component of SWB (i.e., life satisfaction, positive affect, and negative affect) using an equation-by-equation approach (regressions are run separately for different components of SWB) (Dong and Qin, 2017; Liu et al., 2017; White et al., 2017). This may cause the problem of inefficient estimates, as each equation with a different component of SWB contains exactly the same set of right-hand-side variables, and the error term of several equations is statistically correlated (Brenner, 1975; Diener, 1984; Kammann et al., 1979). SURs are thus superior to equation-by-equation OLS regressions in this case, since the SURs generate more efficient estimates than OLS regressions.

3. Data and methods

The objective of this paper was to examine the linkage between access to NOE and SWB in Guangzhou. We used two metrics (streetscape metrics and satellite-derived metrics) to measure participants' access to NOE (i.e., green and blue spaces) in the vicinity of the home. We then estimated the association between access to NOE and each component of SWB using SURs and different NOE access metrics. We further examined the heterogeneous effects by socioeconomic status in these relationships using stratified analyses.

3.1 Study population

The main data used in this research were obtained from a face-to-face survey on community service and quality of life carried out in Guangzhou, China from June to August 2015. Consent was obtained from all subjects prior to conducting the study. This study applied a Probability Proportionate to Population Size (PPS) technique to generate a sample representing the Guangzhou population. Results based on data collected using the PPS sampling technique can be generalised to the overall population in Guangzhou (Bryman, 2016). This survey was sampled via a two-stage sampling method. In the first stage, we applied a multi-stage stratified PPS sampling technique to randomly select 23 residential communities (*she qu*) from seven districts (i.e., Liwan, Yuexiu, Haizhu, Tianhe, Baiyun, Panyu, and Huangpu) in Guangzhou. In the second stage, we used a systematic sampling approach to randomly select 50 households in each sampled community based on residential addresses. Then, we used the Kish Grid method to choose a respondent falling within the age range of 18 to 70 within each sampled household. The total number of valid respondents was 1,150. The survey collected respondents' information on demographic characteristics, socioeconomic status, health status, *hukou* status, housing tenure, neighbourhood satisfaction, and SWB. In addition to the questionnaire survey data, we collected ecological data from the 2010 wave of the China National Population Census Data of Guangzhou, Tencent maps, and a land cover dataset.

3.2 Measures of SWB

From the hedonic view (rather than the eudaimonic view) of wellbeing, this study defines wellbeing in terms of pleasure attainment and pain avoidance (Ryan and Deci, 2001). In light of Diener's conceptual framework, SWB is defined as the self-assessment of an individual's life quality, which encompasses two components, namely the cognitive component and the affective component (Diener, 1984; Diener et al., 1999). The cognitive component (known as life satisfaction) refers to individuals' evaluation of their own life circumstances in the long term, which was estimated using the *Satisfaction with Life Scale* (*SWLS*) (Diener et al., 1985).

Please refer to Appendix Part 1 for a detailed description of the five statements of the *SWLS*. Respondents were required to report on a 7-point Likert scale ranging from "strongly disagree" (value=1) to "strongly agree" (value=7). The total score of an individual's life satisfaction ranged from 5 to 35. For the affective component, respondents were instructed to rate their short-term emotions based on the *Positive and Negative Affect Schedule* (*PANAS*) (Watson et al., 1988). The scale contains 20 items, covering a range of positive affect (e.g., proud and inspired) and negative affect (e.g., afraid and nervous). We recorded respondents' answers on a 5-point Likert scale ranging from 1 ("very slightly or not at all") to 5 ("extremely"). The overall score ranges from 10 to 50 separately for both positive affect and negative affect. Note that a higher score for positive/negative affect indicates a stronger positive/negative affectivity.

3.3 Assessing access to NOE

In our analysis, NOE is considered to consist of green spaces (trees and grasses) and blue spaces (rivers, lakes, and other water bodies) (Nieuwenhuijsen et al., 2014; Triguero-Mas et al., 2015, 2017; Huang et al., 2019). We measured access to NOE using two sets of metrics, namely streetscape metrics and satellite-derived metrics.

3.3.1 Using street-view data and deep learning techniques

We measured individuals' horizontal view of green spaces or blue spaces within a 1,000 m circular buffer around the centroid of an individual's residential community (*she qu*). We utilised street view images within the neighbourhood collected based on Tencent Maps (https://map.qq.com) and deep learning techniques to measure access to NOE (Helbich et al., 2019; Wang et al., 2019a, 2019b). Tencent street view (the Chinese version of Google street view) images are collected by a street view car which has a 360-degree on-board camera. The street imagery was taken in 2016. We eventually collected a total of 41,286 sampling points and 165,144 images. On average, there were 1,795 images from each neighbourhood. Then, we implemented deep learning algorithms for semantic image segmentation (LeCun et al., 2015; Long et al., 2015; Zhou et al., 2016). We assessed an individual's horizontal view of green spaces or blue spaces by averaging the green view index (hereafter, GVI) or blue view index (hereafter, BVI) of all sampling points within his or her residential neighbourhood. The GVI (or BVI) for each sampling point was calculated as the proportion of green space (or blue space) pixels for the corresponding four images. Please refer to Appendix Part 2 for details of the collection of street-view images and the implementation of deep learning algorithms.

3.3.2 The amount of surrounding NOE

We estimated the amount of surrounding greenness and blueness within the 1000 m area buffer around the centroid of participants' residential community based on land cover maps (Gascon et al., 2015). Specifically, the measurement of the amount of surrounding greenness/blueness was estimated by the total area of green/blue spaces within a neighbourhood; these spaces were extracted from the DDT Net For City Map 2016[1]. For the classification of land cover, green spaces included forests, public parks, and other forms of green space, and blue spaces included rivers, lakes, reservoirs, ponds, and oceans. The amount of surrounding greenness/blueness was treated as a continuous variable.

3.4 Covariates

Regressions were adjusted for covariates concerning neighbourhood characteristics and individual characteristics. Regarding neighbourhood characteristics, population density, average annual neighbourhood income per neighbourhood resident, and neighbourhood social cohesion were considered. The population density was calculated as the number of residents per square kilometre within a 1,000 m circular buffer. The average annual neighbourhood income per neighbourhood resident was calculated by averaging all sampled respondents within a community. The neighbourhood social cohesion index was measured at the neighbourhood level based on respondents' responses to five statements concerning neighbourhood attachment, neighbourly reciprocity, community participation, neighbourly

[1] The DDT Net For City Map 2016 is a serial navigation electronic map generated by RITU Corporation Ltd. (http://www.ritu.cn/index.asp) based on the field monitoring data collection method.

interaction, and neighbourhood social control. The five statements are reported in Appendix Part 3. Individual covariates included age, gender, marital status, educational attainment, personal annual income, housing tenure, employment status, social welfare in Guangzhou, *hukou* status, perceived social status, and mental health status (General Health Question-12, GHQ-12). Note that a higher score for GHQ-12 means a poorer mental health status. These covariates were selected based on past works about people's SWB in Chinese cities (Dong and Qin, 2017; Liu et al., 2016, 2017; Ma et al., 2018).

3.5 Statistical analyses

3.5.1 Seemingly unrelated regression (SUR) analysis

SUR was applied in this research to estimate the linkage between access to NOE (i.e., green spaces and blue spaces) and each of three components of SWB simultaneously, namely life satisfaction, positive affect, and negative affect (Zellner, 1962). SURs are superior to OLS regressions in terms of estimate efficiency, as the dependent variables of three equations (i.e., three components of SWB) are assumed to be correlated with each other, and their error terms are assumed to be correlated with each other as well (Brenner, 1975; Diener, 1984; Kammann et al., 1979). We applied the generalised least squares (GLS) approach to conduct the estimation, which is based on the following stacked system (Greene, 2002):

$$\begin{pmatrix} Y_1 \\ Y_2 \\ Y_3 \end{pmatrix} = \begin{pmatrix} X_1 & 0 & 0 \\ 0 & X_2 & 0 \\ 0 & 0 & X_3 \end{pmatrix} \begin{pmatrix} \alpha_1 \\ \alpha_2 \\ \alpha_3 \end{pmatrix} + \begin{pmatrix} \mu_1 \\ \mu_2 \\ \mu_3 \end{pmatrix} = X\alpha + \mu$$

where Y_i = (3×1) vector indicating the scores for life satisfaction, positive affect, and negative affect, respectively,

X_i = (3×K) matrix representing NOE variables and covariates,

α_i = (K×1) vector of estimable coefficients, and

μ_i = error terms.

We assumed that the error terms μ_i were independent across different time periods, but they were correlated with one another contemporaneously. The error items μ_i should meet the following assumptions (Zellner, 1962): 1) $E(\mu_i|X) = 0$; 2) $E(\mu\mu_i'|X) = \sigma_{ij}I_N$; 3) $E\left(\mu_j\mu_{j'}'\middle|X\right) = \sigma_{ij}I_N$; 4) $\Omega = E(\mu\mu') = \sum\otimes\ I_N$.

Variables on the right-hand side included access to NOE and neighbourhood- and individual-level covariates. Note that SURs would be equivalent to equation-by-equation estimation when each equation contains exactly the same set of variables on the right-hand side. Therefore, all variables on the right-hand side are the same across three equations except perceived social status and mental health status (GHQ-12). Earlier studies indicated that perceived social status was related to the cognitive component of SWB (Liu et al., 2017; Schwanen and Wang, 2014), while mental health status was associated with the affective component of SWB (Watson et al., 1988; Zhang and Zhang, 2017). For this reason, these two variables were included in different equations.

3.5.2 Robustness check

SURs were adopted in the present study to generate more accurate estimates. However, it is not clear whether the new model will have a negative impact on the relationships between GVI/BVI and SWB and those between the amount of surrounding greenness/blueness and SWB. Therefore, we conducted robustness tests to check whether the estimated associations were sensitive to changes in model specifications. Specifically, we conducted three separate OLS regressions instead of SURs. Moreover, in light of the uncertain geographic context problem (UGCoP), the correlation between contextual variables and health outcomes could be influenced by the way neighbourhood units are geographically delineated (Kwan, 2012). Existing studies have defined the neighbourhood as buffers of various sizes without a uniform standard (ranging from 30 m to 50 m), thus drawing inconsistent conclusions (Markevych et al., 2017). Accordingly, we conducted sensitivity checks by using a different size of buffer area (i.e. 800 m) to capture respondents' access to NOE and its association with SWB.

3.5.3 Stratified analysis

We assumed that access to NOE would have heterogeneous effects on individuals' SWB, as people with different socioeconomic status would have different opportunities, motivations, and preferences to use green spaces and blue spaces (Lachowycz and Jones, 2013). For example, access to NOE within the neighbourhood may be more influential to lower-income people's SWB than to higher-income people's SWB, as the former group is more sensitive to the friction of distance and less able to use parks far away from home than the latter group. More-educated residents who are more aware of health may be more willing to visit nearby parks and water bodies than their lower-educated counterparts. However, the richer and more educated are busier than the poorer and the less educated, thereby spending less time on NOE near home. Homeowners may be more aware of NOE near their homes than renters, as homeowners tend to have a stronger attachment to the area where they live than renters. By the same token, local residents are assumed to have a higher level of SWB than migrants without a local *hukou* once their surrounding environments improve. To this end, stratified analyses were performed to further explore the heterogeneous effects of socioeconomic status on the association between access to NOE and SWB. Specifically, socioeconomic status indicators included housing tenure (homeowners vs. renters), educational attainment (junior high school or below vs. senior high school or above), *hukou* status (local vs. non-local), and personal yearly income (40,000 RMB or below vs. 40,000 RMB or above). We divided yearly income into two categories – above and below 40,000 – given that the average personal yearly income of Guangzhou residents was around 40,000 RMB at the time of the survey.

4. Results

4.1 Characteristics of sampled communities and population

Table 1 shows the main descriptive statistics for all variables. The average life satisfaction score was 20.8 (SD±5.4), which indicated that Guangzhou residents were neither satisfied nor dissatisfied with their lives[2] (Pavot and Diener, 1993). The average scores for positive affect

[2] Life satisfaction scores of 5 to 35 points. A score of 20 suggests neither satisfaction nor dissatisfaction with life. A score of 26-30 indicates 'extremely satisfied', 21-25 indicates 'slightly satisfied', 15-19 indicates 'slightly

and negative affect among all respondents were 33.5 (SD±6.4) and 18.9 (SD±5.5), respectively. On average, neighbourhood GVI and BVI were 25.6 (SD±6.3) and 0.4 (SD±0.1), respectively, while the areas of surrounding greenness and surrounding blueness were 0.4 km^2 (SD±0.5) and 0.5 km^2 (SD±0.7), respectively. The average levels of population density, annual income per neighbourhood resident, and social cohesion index were 12.0 thousand people per square kilometre (SD±13.7), 58,750.0 yuan (SD±29,399.4), and 16.5 (SD±1.4), respectively. Regarding individual characteristics, around half of the respondents were male (52.3%) and homeowners (54.2%). More than three-quarters of the respondents were aged 30-60 (77.5%), married and living with their spouse (78.2%), and employed (86.1%). About one-third of the respondents had a college education or above, and one-third had a junior high school education. Around 60% of the respondents held a local *hukou*, and nearly 90% had participated in pension or medical insurance schemes. The mean annual income of all respondents was 58,074.9 yuan (SD±78,123.1). Respondents scored an average of 6.2 (SD±1.7) for perceived social status and 22.6 (SD±5.3) for mental health (GHQ12), respectively.

<Insert Table 1 here>

We then conducted a preliminary comparison between two access metrics of NOE using a correlation analysis. The Pearson correlation coefficient between GVI and the amount of surrounding greenness was 0.058 (p=0.048). This weak association may imply that more vegetation along the street is accompanied by a larger amount of greenness within the neighbourhood. There was no significant relationship between BVI and the amount of surrounding blueness (Pearson correlation: -0.0227, p=0.442). This reflects the fact that streetscape blue view is very different from people's actual exposure to blue spaces on the street, as waterfront pedestrian walkways and waterfront vegetation may block the view of water bodies (e.g. rivers and lakes) along traffic lanes.

dissatisfied', and 5-9 indicates 'extremely dissatisfied' (Pavot and Diener, 1993).

4.2 Seemingly unrelated regressions

We justified the use of the SURs instead of OLS regression by examining the heteroscedasticity of three separate regression models. The result of the Breusch-Pagan test (chi square=105.56, p=0.00) indicated that the error terms of the three regressions were correlated to each other, and that the SURs had more explanatory power than the OLS models. We then tested the multi-collinearity of variables on the right-hand side. The VIF test (VIF<10) indicated that correlations among these variables had not biased the parameter estimates of the model. The results from the SURs are presented in Table 2. Models 1a, 1b, and 1c separately regressed each component of SWB on NOE access indicators (i.e., GVI, BVI, the amount of surrounding greenness/blueness) and covariates.

<Insert Table 2 here>

As shown in Models 1a, 1b, and 1c, GVI within the circular buffer of 1,000 m was significantly related to a lower level of negative affect (β=-10.293, p<0.01). The amount of surrounding greenness within the same circular buffer was found to be linked to a lower level of negative affect (β=-0.834, p<0.01). Neither GVI nor the amount of surrounding greenness was significantly related to a higher level of life satisfaction or to a higher level of positive affect. BVI was significantly associated with a higher level of life satisfaction (β=192.529, p<0.1). The amount of surrounding blueness was related to a higher level of life satisfaction (β=0.497, p<0.1) and a higher level of positive affect (β=0.865, p<0.01). Neither BVI nor the amount of blueness was significantly related to a lower level of negative affect.

In terms of covariates, population density was related to a higher level of positive affect and a lower level of negative affect. Both average annual neighbourhood income and neighbourhood social cohesion index were related to a higher level of life satisfaction. Negative affect increased with age. Male respondents reported a lower level of positive affect than their female counterparts. Those who had college education or above and who owned the home in which they lived tended to report a higher level of life satisfaction and a higher level of positive affect than those with lower educational attainment and without the homeownership. Personal annual income was linked to a higher level of life satisfaction. Being unemployed was linked to a lower level of positive affect. Perceived social status was associated with a higher level of life satisfaction. Mental health was linked to a higher level of positive affect and a lower level of negative affect.

4.3 Robustness check

The results of sensitivity analysis based on the OLS regressions are illustrated in Table 3. It is evident that the associations between access to green spaces (blue spaces) and each component of SWB remain the same, when OLS regressions instead of SURs are fitted. Results from the sensitivity check with the 800 m buffer areas also indicate similar associations to those derived from SURs with the 1000 m buffer areas (Table 4). Specifically, regardless of the use of the model and buffer size, it was found that both GVI and the amount of surrounding greenness were significantly related to a lower level of negative affect. BVI was linked to a higher level of life satisfaction. The amount of surrounding blueness was associated with a higher level of life satisfaction and a higher level of positive affect.

<Insert Tables 3 and 4 here>

4.4 Stratified analysis

Results from stratified analyses are presented in Table 5. We merely report relationships at the 0.05 significance level. For housing tenure stratified analyses, two indicators regarding access to green spaces (i.e., GVI and the amount of surrounding greenness) were related to a lower level of negative affect among homeowners (β=-17.436, p<0.01; β=-1.339, p<0.01, respectively), while the amount of surrounding blueness was associated with a higher level of life satisfaction (β=1.449, p<0.01) and a higher level of positive affect (β=1.012, p<0.05) among renters.

<Insert Table 5 here>

For the educational attainment stratified analyses, GVI was linked to a lower level of negative affect among those who had a junior high school education or below (β=-19.549, $p<0.01$). BVI was associated with a higher level of positive affect among residents with a lower level of education (β=526.514, $p<0.05$). The amount of surrounding blueness was associated with a higher level of life satisfaction (β=0.747, $p<0.05$) and a higher level of positive affect (β=1.061, $p<0.01$) for the higher-educated.

For the *hukou* status stratified analyses, the association between GVI and a lower level of negative affect was observed for both locals and migrants (β=-16.929, $p<0.01$, β=-9.746, $p<0.05$). The amount of surrounding greenness was linked to a higher level of life satisfaction among migrants (β=1.133, $p<0.05$) and a lower level of negative affect among locals (β=-1.167, $p<0.01$). BVI was found to be linked to a higher level of life satisfaction for locals (β=447.687, $p<0.05$), and the amount of surrounding blueness was related to a higher level of life satisfaction for migrants (β=1.544, $p<0.01$) and a higher level of positive affect for locals (β=1.160, $p<0.01$).

For the income stratified analyses, associations were found between GVI and a lower level of negative affect for both higher-income and lower-income groups (β=-10.556, $p<0.05$ and β=-15.448, $p<0.01$, respectively). The amount of surrounding greenness was associated with a higher level of life satisfaction and a lower level of negative affect among the lower-income group (β=1.378, $p<0.05$ and β=-1.333, $p<0.05$, respectively). BVI was linked to a higher level of life satisfaction among the higher-income group and a higher level of positive affect among the lower-income group (β=342.605, $p<0.05$ and β=435.564, $p<0.05$, respectively). The amount of surrounding blueness was linked to a higher level of life satisfaction for those who earned more than 40,000 RMB yearly (β=0.914, $p<0.05$). Given that the way of classifying sample members in different categories might influence the results of stratified analysis, we conducted a sensitivity analysis by adjusting the income cut-off to 35,000 RMB and 45,000 RMB yearly. Results of this sensitivity analysis suggest that adjusting the income cut-off would not cause a substantial change in our conclusion (results are available upon request).

5. Discussion

This paper makes the first attempt in the high-density urban context of China to investigate the linkage between access to NOE (namely, green spaces and blue spaces) and each component of SWB (namely, life satisfaction, positive affect, and negative affect) using the combination of a seemingly unrelated regression model and two access metrics of NOE. We found a weak positive association between two metrics of blue spaces and life satisfaction. We also found a strong linkage between the amount of surrounding blueness and a higher level of positive affect. Access to green spaces was related to a lower level of negative affect. No significant relationship was observed between access to blue spaces and negative affect, or between access to green spaces and life satisfaction. Results from heterogeneity checks showed that NOE-SWB relationships varied by individuals' socioeconomic status (in this case, income, education, homeownership, and *hukou* status). Given that streetscape access metrics and satellite-derived access metrics may represent different aspects of NOE accessibility, our results suggest that different people's cognitive evaluations of the quality of their lives, positive emotions, and negative emotions are shaped by different types of NOE access (i.e., viewing vegetation or water bodies on the street versus residing in neighbourhoods with extensive green/blue spaces).

5.1 Access to green spaces and SWB

Regardless of which access metrics were used, we found no evidence that more access to urban greenery was linked to more satisfaction with life. Prior studies in Western countries such as the UK, Australia, and New Zealand have suggested a promoting effect of residents' access to green spaces on life satisfaction (Ambrey and Fleming, 2014; Fleming et al., 2016; Mavoa et al., 2019a; White et al., 2013b). In these studies, the level of access to green spaces was assessed using the Normalized Difference Vegetation Index (NDVI) (Mavoa et al., 2019a), the percentage of green spaces (Ambrey and Fleming, 2014; White et al., 2013b), perceived access to green spaces (Fleming et al., 2016), and the frequency of greenspace visits (Mavoa et al., 2019a). Inconsistent with other studies, a study of an adult English population failed to find a significant impact of the percentage of green spaces within a residential neighbourhood on life satisfaction (evaluative wellbeing) when area, individual, and time-related controls were adjusted for (White et al., 2017). Three studies in China have shown a correlation between residential proximity to public green spaces and a higher level of life satisfaction (Dong and Qin, 2017; Ma et al., 2018; Wu et al., 2019a). One pathway linking proximity to public green spaces to SWB is the value of housing property. Closer proximity to green spaces may lead to the appreciation of nearby residential property values, which may increase their owners' life satisfaction (Wu et al., 2019a). Another pathway that has been found to link proximity to green spaces to SWB is residential satisfaction, which is one of several domains of life satisfaction (Ma et al., 2018; Wu et al., 2020). However, no prior research has investigated whether increased residential surrounding greenness is associated with more satisfaction with life for a Chinese population, and the present study provides no evidence of this association either.

Negative affectivity is connected with mental illness and mental disorder (Watson et al., 1988). In line with prior studies on the mitigating effect of urban greenery on the symptoms of mental illness (e.g., depression and anxiety) in Western countries and in China (Bratman et al., 2015; Cohen-Cline et al., 2015; Helbich et al., 2019; Li et al., 2019; Liu et al., 2019b; Mavoa et al., 2019b; McEachan et al., 2016; Sarkar et al., 2018), the current study indicated that access to urban greenery alleviated negative emotions and moods such as feeling, distressed, upset, afraid, and nervous. We did not observe a significant relationship between more access to urban greenery and higher positive affect. One possible explanation was that nature areas of different types and locations will evoke different categories of emotions, which was demonstrated by a psychological and spatial study conducted in the Netherlands (Davis et al., 2016). Nevertheless, experimental studies in North America and Europe have evidenced that engagement with nature (e.g., parks and gardens) increases participants' positive affect and brings about positive moods (Berman et al., 2012; Hartig et al., 2003;

McMahan and Estes, 2015). Similarly, one cross-sectional study with objective measures of access to NOE conducted in four European cities found a positive association between NOE exposure and positive affect (Kondo et al., 2019). Overall, results from prior studies on the relationship between access to NOE and emotions were inconclusive (Kondo et al., 2018). More studies are needed to investigate the association between greenery and positive affect using other datasets collected in other areas of China.

5.2 Access to blue spaces and SWB

Our research indicated that access to blue spaces was associated with a higher level of life satisfaction, which was consistent with our expectation. Housing property values and waterfront amenities may play a role in mediating the relationship between access to blue spaces and life satisfaction. Additionally, there is evidence that exposure to blue spaces arouses feelings of awe, and thus contributes to higher levels of wellbeing (Anderson et al., 2018). We observed a positive linkage between access to blue spaces and positive affect when satellite-derived metrics were used but no significant relationship when streetscape metrics were used. A possible explanation for the stark contrast between the two types of metric is that streetscape metrics might not accurately measure the extent to which residents have access to blue spaces within their neighbourhood, and satellite-derived metrics turn out to be a better indicator in this regard. Specifically, street-view imagery was taken on traffic lanes along the road network, and it was always the case that waterfront pedestrian walkways and waterfront vegetation blocked the view of water bodies. By contrast, the number of water bodies can more accurately capture the salutogenic effect of blue spaces (i.e., mitigating environmental hazards, facilitating social interaction, and encouraging physical activity). For this reason, as shown in Table 1, the variation between neighbourhoods in BVI is much smaller than that in residential surrounding blueness, and the association between BVI and positive affect is not prominent.

We found no evidence that access to blue spaces was significantly associated with the level of negative affect. This finding is in line with findings from prior studies in Spain and New

Zealand that access to blue spaces exerted statistically insignificant effects on distress, depression, and anxiety, which are connected to negative emotions (Gascon et al., 2015, 2018; Mavoa et al., 2019b). Only two studies suggested that increased access to blue spaces was linked to decreased mental disorders. One study conducted in Wellington, New Zealand, demonstrated that visibility of blue spaces had a significantly positive correlation with lower psychological distress (Nutsford et al., 2016). Another study on older adults living in Beijing, China, indicated that increased access to street-view blue spaces was associated with a lower rate of depression (Helbich et al., 2019). There is scant literature on the impact of access to blue spaces on negative affectivity, and more empirical evidence is needed to unravel the correlation between the two. Regarding the composited effect of both green and blue spaces, inconsistent with previous studies, we found that both green and blue spaces were positively associated with SWB. This may be because Guangzhou is a waterfront city with a marine culture, so people living in Guangzhou tend to value the water body and regard it as an important natural element in their daily leisure activities. However, since blue spaces are usually surrounded by green spaces, our finding still cannot infer the existence of the composited effect of both green and blue spaces.

5.3 Stratified by socioeconomic status

Results from stratified analyses indicated that association between access to green spaces and life satisfaction was stronger for migrants and lower-income groups, probably because low-income people and migrants tend to have better access to inner-city public parks than high-income people and locals in Chinese large cities (Huang et al., 2019; Xiao et al., 2017), and their satisfaction with life is more related to their satisfaction with their immediate residential environment (Liu et al., 2017; Lin and Huang, 2018). The association between access to green space and negative affect was stronger for homeowners, locals and lower-educated groups, probably because they tend to spend more time in viewing surrounding vegetation, socializing with their neighbours and conducting physical activity within the neighbourhood (instead of somewhere far away) than their counterparts, which play an important role in preventing negative affect.

The BVI-life satisfaction linkage was stronger for locals and higher-income groups. This suggests that a better view of water bodies (e.g. rivers and lakes) would increase local and higher-income residents' satisfaction with life, as a view of water bodies is more related to their evaluation of neighbourhoods. By contrast, the relationship between BVI and positive affect was stronger for lower-educated and lower-income groups, probably because lower-educated and lower-income people are more likely to travel by public transport or by walking/cycling than their higher-educated and higher-income counterparts, and viewing blue spaces unintentionally during daily travel would generate positive affect. The amount of surrounding blueness was more related to the life satisfaction of renters, the higher-educated, migrants, and the higher-income and was more related to the positive affect of renters, the higher-educated, and locals. As waterfront properties have the highest housing price in the city of Guangzhou, the majority of residents living in waterfront neighbourhoods are the higher-income and higher-educated, who are more willing to conduct physical and recreational activities along river banks and lake shores than the poorer and the less-educated. The reason behind the differences between locals and migrants and between homeowners and renters in the surrounding blueness-life satisfaction/positive affect relationship is unknown.

5.4 Policy implications

This study attempts to provide policymakers, urban planners, and landscape architects with potentially important insights regarding how to interweave wellbeing promotion with NOE improvement in Chinese high-density cities. Specifically, it is suggested that policymakers and planners achieve equitable distribution of green spaces and blue spaces among different social groups. They are particularly advised to place more emphasis on the development of small patches of green/blue spaces in high-density inner cities. Besides, findings from the current study offer evidence on how landscapes can be designed and constructed to encourage people to spend more leisure time in contact with nature, thereby improving their SWB.

5.5 Limitations

This study has several limitations. First, the cross-sectional nature of the data used in the study was not conducive to disentangling the potential causal relationship between NOE access and SWB. Second, we focused on the quantity of NOE instead of the quality of NOE, which was found to be influential on residents' health (de Vries et al., 2013; Francis et al., 2012). Third, we did not consider personality traits in the analysis due to the unavailability of relevant data. Omitting variables regarding personality traits might cause bias in regression estimates. Fourth, residential selection bias might lead to overestimation in the NOE-SWB linkage. For example, people who were optimistic about their future tended to be more satisfied with life and were more inclined to live in neighbourhoods with better access to NOE. Fifth, street-view data have some limitations when they are used to measure residents' access to NOE. One limitation is that street space represents only a fraction of the activity space that people are exposed to in their daily lives; another limitation is that street views actually capture how people view their surroundings from traffic lanes instead of from their associated pavements. Sixth, neither GVI (or BVI) nor surrounding greenness (or blueness) can fully represent residents' actual access to NOE, because these indices do not measure residents' time spent at green/blue spaces (for example, how often they visit green/blue spaces and how long they spend on their visits).

6. Conclusion

Our findings indicated that streetscape access metrics and satellite-derived access metrics captured different aspects of NOE, which were linked to different components of SWB. Specifically, GVI and the amount of surrounding greenness were related to a lower level of negative affect, and BVI and the amount of surrounding blueness were associated with more satisfaction with life. The amount of surrounding blueness was linked to a higher level of positive affect. Especially, we found that the relationship between access to NOE and people's SWB in the high-density urban context of China is different from what has been observed in Western countries. Regardless of which metrics were used (i.e., streetscape or satellite), our study provided no evidence that increased access to green space was significantly related to a higher level of life satisfaction and a higher level of positive affect in Chinese cities. This discrepancy may be partly due to the fact that Chinese people generally spend less time at public green space and have less intention to visit green space for recreational purposes than people from Western countries, and intentional visits to green space have a stronger impact on life satisfaction and positive affect than unintentional exposure (e.g. viewing avenue trees on the way to work). Another explanation is that Asian culture shapes the specific affective states that Chinese people desire, such as a sense of calm and peace (Tsai, 2007).

Declaration of interests

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author Statement

Ye Liu and Yuqi Liu designed the study. Tong Xiao and Yuqi Liu derived satellite metric data and conducted the statistical analysis. Yao Yao and Ruoyu Wang derived streetscape metric data. Ye Liu drafted the manuscript with contribution from Tong Xiao, Yuqi Liu, Yao Yao, and Ruoyu Wang. All authors contributed to the revision of manuscript.

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Table 1. The descriptive statistics of the variables

Variables	N	Proportion/Mean (SD)
Dependent variables		
Life satisfaction (5-35)	1150	20.8 (5.4)
Positive affect (10-50)	1150	33.5 (6.4)
Negative affect (10-50)	1150	18.9 (5.5)
Independent variables		
Green view index (GVI, 1000 m) (0-100)	1150	25.6 (6.3)
Blue view index (BVI, 1000 m) (0-100)	1150	0.4 (0.1)
Surrounding greenness (1000 m) (km^2)	1150	0.4 (0.5)
Surrounding blueness (1000 m) (km^2)	1150	0.5 (0.7)
Covariates		
Population density (thousand people per square kilometre)	1150	12.0 (13.7)
Average annual neighbourhood income per neighbourhood resident (CNY)	1150	58,750.0 (29,399.4)
Neighbourhood social cohesion	1150	16.5 (1.4)
Age (%)		
18-30	213	18.5
30-60	897	77.5
⩾ 60	46	4.0
Gender (%)		
Male	601	52.3
Female	549	47.7
Marital status (%)		
Married and living together	899	78.2
Single, divorced, and widowed	230	20.0
Married and living apart	21	1.8
Educational attainment (%)		
Junior high school or below	366	31.8
High school	385	33.5
College or above	399	34.7
Personal annual income (CNY)	1150	58,074.9 (78,123.1)
Housing tenure (%)		
Homeowner	623	54.2
Renter	527	45.8
Employment status (%)		
Employed	990	86.1

	N	% / Mean (SD)
Unemployed	160	13.9
Social welfare in Guangzhou (%)		
Participating in all or some insurance schemes	998	86.8
Not participating in any pension or insurance schemes	152	13.2
Hukou status (%)		
Local hukou	683	59.4
Non-local hukou	467	40.6
Perceived social status (1-10)	1150	6.2 (1.7)
Mental health (GHQ-12) (12-48, scored inversely)	1150	22.6 (5.3)

Note: GHQ-12 = 12-item General Health Questionnaire. N = number of respondents; SD = Standard Deviation.

Table 2. Results of Seemingly unrelated regressions of different dimensions of subjective well-being

	Model 1a		Model 1b		Model 1c	
	Life satisfaction		Positive affect		Negative affect	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Independent variables						
Green view index (GVI, 1000 m)	1.400	3.558	-13.778***	4.157	-10.293***	3.423
Surrounding greenness (1000 m)	0.455	0.340	-0.677*	0.395	-0.834**	0.325
Blue view index (BVI, 1000 m)	192.529*	114.138	148.799	132.844	113.855	109.357
Surrounding blueness (1000 m)	0.497*	0.270	0.865***	0.311	-0.197	0.256
Covariates						
Population density (1000 m)	-0.103	0.136	0.546***	0.157	-0.379***	0.129
Average annual neighbourhood income per neighbourhood resident (log)	2.326***	0.437	-0.959*	0.509	1.710***	0.419
Neighbourhood social cohesion	0.252*	0.138	0.204	0.159	0.580***	0.131
Age	0.012	0.018	-0.030	0.021	-0.048***	0.018
Gender (reference group: male)						
Female	0.240	0.300	-0.747**	0.349	-0.132	0.288
Marital status (reference group: married and living together)						
Single	0.182	0.409	-0.021	0.473	0.095	0.389
Married and living apart	-0.518	1.112	0.941	1.289	1.082	1.062
Educational attainment (reference group: high school)						

Junior high school or below	-0.260	0.385	-0.032	0.446	0.123	0.367
College or above	1.157***	0.405	1.213***	0.470	0.397	0.387
Personal annual income (log)	0.133**	0.066	0.029	0.077	0.025	0.063
Housing tenure (reference group: renter)						
Homeowner	1.652***	0.416	1.460***	0.476	-0.220	0.392
Employment status (reference group: employed)						
Unemployed	0.598	0.519	-1.527**	0.603	0.308	0.497
Social welfare in Guangzhou (reference group: interviewees participating in all or some insurance schemes)						
Not participating in any pension or insurance schemes	0.559	0.492	0.260	0.567	1.037**	0.467
Hukou status (reference group: interviewees without Guangzhou hukou)						
Guangzhou hukou status	-0.469	0.424	-1.149**	0.493	-0.661	0.406
Perceived social status	0.418***	0.090				
Mental health (scored inversely)			-0.418***	0.032	0.474***	0.027
Constant	5.769**	2.619	44.314***	2.934	0.695	2.418
Number of cases	1150		1150		1150	
R^2	0.163		0.207		0.265	

Note: Significance levels: * p<0.10, ** p<0.05, *** p<0.01. S.E. = standard error.

Table 3. Results of the robustness check using ordinary least square regression

	Model 2a		Model 2b		Model 2c	
	Life satisfaction		Positive affect		Negative affect	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 1000 m)	1.378	3.589	-14.043***	4.195	-10.376***	3.453
Surrounding greenness (1000 m)	0.434	0.343	-0.681*	0.398	-0.835**	0.328
Blue view index (BVI, 1000 m)	192.427*	115.144	145.398	134.020	112.786	110.321
Surrounding blueness (1000 m)	0.453*	0.270	0.867***	0.314	-0.196	0.258
Covariates	Yes		Yes		Yes	
Constant	4.749*	2.651	44.753***	2.964	0.833	2.440
Number of cases	1150		1150		1150	
R^2	0.164		0.207		0.265	

Models are adjusted for all covariates. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. S.E. = standard error.

Table 4. Results of the sensitivity check with 800-meter buffer NOE characteristics

	Model 3a		Model 3b		Model 3c	
	Life satisfaction		Positive affect		Negative affect	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 800 m)	4.618	4.278	-2.003*	0.999	-4.165***	1.115
Surrounding greenness (800 m)	0.722	0.498	-0.676*	0.263	-1.093***	0.381
Blue view index (BVI, 800 m)	197.148*	102.069	264.593	195.683	167.594	136.369
Surrounding blueness (800 m)	0.749**	0.306	1.267***	0.352	-0.101	0.290
Covariates	Yes		Yes		Yes	
Constant	6.918***	2.586	42.878***	2.888	-0.117	-2.379
Number of cases	1150		1150		1150	
R^2	0.163		0.204		0.263	

Models are adjusted for all covariates. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. S.E. = standard error.

Table 5. Results of heterogeneous effects by socioeconomic status using stratified analysis

	Life satisfaction				Positive affect				Negative affect			
	Model 4a-1		Model 4a-2		Model 4b-1		Model 4b-2		Model 4c-1		Model 4c-2	
Housing tenure	Homeowners		Renters		Homeowners		Renters		Homeowners		Renters	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 1000 m)	-3.893	5.499	2.702	5.090	-22.424***	6.385	-9.507	5.969	-17.436***	5.324	-7.905*	4.800
Surrounding greenness (1000 m)	0.051	0.404	1.325*	0.682	-1.141**	0.468	0.346	0.792	-1.339***	0.390	0.339	0.637
Blue view index (BVI, 1000 m)	312.003*	177.444	78.763	167.212	291.104	205.628	55.296	193.830	315.597*	171.466	-33.327	155.855
Surrounding blueness (1000 m)	-0.183	0.351	1.449***	0.440	0.663	0.405	1.012**	0.507	-0.148	0.337	-0.322	0.408
Covariates	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	0.911	4.324	12.668***	3.989	38.511***	4.928	49.279***	4.408	-10.898***	4.119	8.408**	3.546
Number of cases	623		527		623		527		623		527	
R^2	0.148		0.077									
	Model 5a-1		Model 5a-2		Model 5b-1		Model 5b-2		Model 5c-1		Model 5c-2	
Educational attainment	Junior high school or below		Senior high school or above		Junior high school or below		Senior high school or above		Junior high school or below		Senior high school or above	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 1000 m)	0.012	6.272	5.291	4.510	-20.283***	7.401	-10.794**	5.242	-19.549***	5.388	-5.399	4.466
Surrounding greenness (1000 m)	1.286	0.963	0.419	0.370	-1.177	1.129	-0.690	0.428	-1.366*	0.821	-0.626*	0.365
Blue view index (BVI, 1000 m)	-10.281	224.991	202.732	140.057	526.514**	264.862	23.284	162.463	572.761***	192.726	-93.917	138.398
Surrounding blueness (1000 m)	0.369	0.493	0.747**	0.339	0.041	0.571	1.061***	0.389	-0.748*	0.416	0.067	0.332
Covariates	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	-3.101	4.951	9.228***	3.246	44.287***	5.664	44.359***	3.643	1.872	4.127	-0.131	3.107
Number of cases	366		748		366		748		366		748	
R^2	0.143		0.148									
	Model 6a-1		Model 6a-2		Model 6b-1		Model 6b-2		Model 6c-1		Model 6c-2	
Hukou status	Locals		Migrants		Locals		Migrants		Locals		Migrants	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 1000 m)	-7.509	5.557	5.054	5.007	-15.841**	6.466	-18.849***	5.953	-16.929***	5.277	-9.746**	4.926
Surrounding greenness (1000 m)	-0.061	0.467	1.133**	0.509	-0.791	0.542	-0.534	0.602	-1.167***	0.443	-0.182	0.498
Blue view index (BVI, 1000 m)	447.687**	181.030	4.387	151.698	332.334	210.813	39.949	179.176	288.066*	172.066	113.394	148.212
Surrounding blueness (1000 m)	-0.148	0.349	1.544***	0.434	1.160***	0.399	0.275	0.511	-0.546*	0.326	0.365	0.423
Covariates	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	-3.475	4.485	12.173***	3.704	35.957***	5.098	47.010***	4.219	-9.038**	4.166	5.600	3.495
Number of cases	683		467		683		467		683		467	
R^2	0.171		0.184									

Personal yearly income	Model 7a-1		Model 7a-2		Model 7b-1		Model 7b-2		Model 7c-1		Model 7c-2	
	40,000 RMB or below		40,000 RMB or above		40,000 RMB or below		40,000 RMB or above		40,000 RMB or below		40,000 RMB or above	
	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.	Estimate	S.E.
Green view index (GVI, 1000 m)	5.520	4.693	1.331	5.764	-16.903***	5.551	-12.851*	6.791	-10.556**	4.464	-15.448***	5.722
Surrounding greenness (1000 m)	1.378**	0.631	0.350	0.404	-1.737**	0.741	-0.232	0.475	-1.333**	0.596	-0.713*	0.400
Blue view index (BVI, 1000 m)	-116.597	164.142	342.605**	164.377	435.564**	193.671	-137.726	193.330	207.404	155.734	126.472	162.876
Surrounding blueness (1000 m)	0.605*	0.345	0.914**	0.449	0.724*	0.400	0.954*	0.525	-0.367	0.322	0.003	0.443
Covariates	Yes		Yes		Yes		Yes		Yes		Yes	
Constant	4.770	3.459	9.050**	3.813	38.979***	3.911	49.482***	-4.354	1.168	3.147	-2.571	3.676
Number of cases	655		495		655		495		655		495	
R^2	0.136		0.202									

Models are adjusted for all covariates. Significance levels: * p<0.10, ** p<0.05, *** p<0.01. S.E. = standard error. P values are available upon request.