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Moderation effect of visible urban greenery on the association between neighbourhood deprivation and subjective well-being: Evidence from Hong Kong

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HIGHLIGHTS

- We examined the relationship among neighbourhood deprivation, urban greenery, and subjective well-being.
- Social fragmentation was negatively associated with subjective well-being.
- Higher level of overall greenery and visible greenery were associated with higher subjective well-being.
- Only visible greenery mitigates the negative effect of social fragmentation on subjective well-being.
- The importance of visible greenery in creating healthy city should be noted.

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ABSTRACT

The well-being benefit of urban greenery has been extensively documented broadly, though less is known about its moderation effect on the relationship between neighbourhood deprivation and subjective well-being. Some scholars also argued that the inconclusive associations between urban greenery and subjective well-being might be partially attributed to the various measuring methods of greenery and the difficulty to measure visible greenery objectively. In this study, we applied three approaches to objectively measure different aspects of urban greenery, including overall greenery by Normalized Difference Vegetation Index (NDVI), visible greenery by Google Street View (GSV) images, and park proximity by geospatial data. We captured two dimensions of neighbourhood deprivation: socio-economic disadvantage and social fragmentation. Using data from the first wave (2015) of the Hong Kong Panel Survey for Poverty Alleviation (N = 1752), the association between urban greenery, neighbourhood deprivation, and subjective well-being was investigated with multilevel linear regression models, while controlling other covariates. We found that subjective well-being level was negatively associated with social fragmentation but no socio-economic disadvantages, while positively associated with overall greenery and visible greenery. Additional moderation effect analysis reveals that the negative linkage between social fragmentation and subjective well-being was significantly mitigated by visible greenery. These findings demonstrated the importance of visible greenery in enhancing subjective well-being, especially for residents in deprived neighbourhoods, and offered new insights to support urban planning and public health strategies to create a healthy living environment.

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1. Introduction

Subjective well-being (SWB) is defined as "how individuals subjectively evaluate or appraise their own lives" (National Research Council, 2014). People who experience satisfied life, frequent positive emotion and infrequent unpleasant emotions tend to have high subjective well-being (Diener, Suh, & Oishi, 1997). Subjective well-being has been widely acknowledged as associated with better personal health, longevity, and higher social productivity (Diener, 2009; Diener, Pressman, Hunter, & Delgadillo-Chase, 2017). Hence, the determinants of subjective well-being have been extensively studied in psychology, sociology, economic and public health since the 1960s (Diener et al., 1997; Easterlin, 2001), for example, individual-level demographic characteristics, economic and employment status (Diener et al., 1997; Easterlin, 2001). The significance of neighbourhood in shaping health and well-being has been proposed by researchers from geography since the 2000s, suggesting that the inequitable access to social and environmental resource may lead to the inequalities in health and well-being outcomes as well, and such effect would be greater among people in socioeconomic deprived neighbourhoods (Ballas & Tranmer, 2012; Cramm, Møller, & Nieboer, 2012; Mouratidis, 2021; Veenhoven, 2015).

The existing body of research demonstrates that neighbourhood deprivation, such as socio-economic disadvantage, social fragmentation, and disorder, is negatively associated with residents' life satisfaction, well-being and health outcomes (Bagheri et al., 2019; Bellani & D'Ambrosio, 2011; Ivory, Collings, Blakely, & Dew, 2011; Ludwig et al., 2012; Oishi, Kesebir, & Diener, 2011; Orben, Tomova, & Blakemore, 2020). Researchers in United State found an increase in subjective well-being among people who moved to a less socio-economic disadvantaged neighbourhood (Ludwig et al., 2012), and an increase in Gini coefficient was associated with a higher odds of reporting poor self-rated health (Subramanian & Kawachi, 2003). A comparative study conducted in England and Wales also shown a negative association between neighbourhood deprivation and life satisfaction (Knies, Melo, & Zhang, 2021). In the Asian context, neighbourhood deprivation was reported as negatively associated with subjective well-being level in Guangzhou (Liu, Zhang, Liu, Li, & Wu, 2017), and two studies conducted in Hong Kong showed that community-level socio-economic disadvantage and fragmentation were associated with an increased risk in cancer mortality and suicide (Hsu, Chang, Lee, & Yip, 2015; Wang et al., 2021).

Meanwhile, considerable literature has evolved around the theme of the restoration and recovery effect of the natural environment, especially the exposure to greenery, on emotion and health outcomes (Hartig, Mitchell, De Vries, & Frumkin, 2014; Keniger, Gaston, Irvine, & Fuller, 2013). It has been observed that contact with greenness may reduce the prevalence of, or mitigate, depression, anxiety, and stress levels (Grahn & Stigsdotter, 2010; Nisbet, Zelenski, & Murphy, 2011; Passmore & Howell, 2014; Pun, Manjourides, & Suh, 2018). Such benefit may be even stronger for people who have experienced a stressful event or lived in deprived neighbourhoods (Roe, Aspinall, & Ward Thompson, 2017; van den Berg, Maas, Verheij, & Groenewegen, 2010; Yang et al., 2020). Mitchel and Popham first articulated the buffering or mitigating effect of urban greenery on health inequalities as 'equigenesis' theory (Mitchell & Popham, 2008). They proposed that a good access to greenspace may become a 'equigenic' role, to disrupt the conversion from social inequalities to health inequalities (Mitchell & Popham, 2008; Mitchell, Richardson, Shortt, & Pearce, 2015).

However, the health-promoting association between greenery and subjective well-being was inconclusive. Some empirical studies have reported non-significant or even negative associations. Previous research suggested that the inconclusive results might partially be attributed to the inconsistent and/or compromised measuring approaches to urban greenery (Alcock et al., 2015; James, Banay, Hart, & Laden, 2015; Lachowycz & Jones, 2011; Zhang, Zhou, & Kwan, 2019). The mainstream measurements have highly relied on remote sensing images or two-dimensional geospatial data which cannot represent the daily perception of urban greenery at the eye level (Villeneuve et al., 2018; Ye et al., 2019). Thus, it is crucial to understand the effect of different urban greenery measurements on subjective well-being.

In summary, existing literature provides strong evidence of the positive effect of urban greenery and adverse effect of neighbourhood deprivation on subjective well-being, yet less is known about whether urban greenery will mitigate the detrimental impact of neighbourhood deprivation on subjective well-being. Furthermore, the majority of existing studies focused on western society (Cartwright, White, & Clitherow, 2018; van den Berg et al., 2010). Less is known about the complex relationships among neighbourhood deprivation, urban greenery and subjective well-being in an Asian context. In this study, we used Hong Kong as a case study, which is an affluent city with grim income inequality and well-being status (Kühner, Lau, & Addae, 2021; Lai, Yu, & Woo, 2020; The World Bank, 2022). As one of the most unequal regions of the world, Hong Kong owned a high Gini coefficient of 0.54 in 2016 and a high poverty rate of 23.6 % in 2020 (Census and Statistics Department, 2017; Census and Statistics Department, 2021). Compared with other affluent societies, the quality of life in Hong Kong remained in the lowest quantiles with ranked 81st on happiness index (Helliwell, Huang, Wang, & Norton, 2022).

Therefore, the current study has two objectives: 1) to examine the complex relationships among neighbourhood deprivation, urban greenery and subject well-being in Hong Kong; 2) to discover whether the associations between neighbourhood deprivation and subjective well-being vary by urban greenery.

2. Literature review

2.1. Neighbourhood deprivation and subjective well-being

Living in a deprived neighbourhood is associated with worse subjective well-being (Sampson, 2003; Wilson, 2012). Over the years, researchers have been interested in studying which aspects of neighbourhood deprivation matter for individuals' well-being. Visser et al. (2021) distinguished three dimensions of neighbourhood deprivation linked to subjective well-being: neighbourhood socioeconomic disadvantage, neighbourhood social environment and neighbourhood disorder. Neighbourhood socioeconomic disadvantage has been measured by indicators such as poverty rate, economic inequality, unemployment rate, the proportion of elderly adults, and female-head households (Brazil & Clark, 2017; Muramatsu, 2003). Some studies also developed a deprivation index to assess the socioeconomic disadvantage of the neighbourhood (Astell-Burt, Maynard, Lenguerrand, & Harding, 2012; Bonomi Bezzo, Silva, & Van Ham, 2021). In Hong Kong, a lower level of life satisfaction was found in individuals living in neighbourhoods with higher poverty rates and higher deprivation scores, measured by education level, professional job, public housing and overcrowding of living spaces (Hsu, Chang, & Yip, 2017). Another dimension of neighbourhood deprivation is social environment, which is associated with higher levels of social fragmentation or lower level of social cohesion. Bagheri et al. (2019) found that higher levels of social fragmentation, measured by family structure and mobility, was associated with higher prevalence of depression in Australia. Yu et al. (2021) investigated the association between neighbourhood social cohesion, mainly measuring one's interactions with neighbours, and loneliness among older adults in Hong Kong. They found that a higher level of neighbourhood social cohesion was associated with lower levels of loneliness. Such association was more pronounced among the low-and-middle class than the high-class. Neighbourhood disorder refers to the "observed or perceived physical and social features of neighbourhoods that may signal the breakdown of order and social control (Gracia, 2014). Indicators such as level of safety, crime rate, and level of violence have been used to measure neighbourhood disorder (Barr, 2018; Odgers, Caspi, Bates, Sampson, & Moffitt, 2012). Scales such as perceived neighbourhood disorder developed by Ross and Mirowsky (1999) and

Systematic Social Observation developed by Sampson and Raudenbush (1999) have also been widely used to evaluate neighbourhood disorder. Visser et al. (2021)'s systematic review showed that most studies reported a negative effect that neighbourhood disorder imposes on people's well-being. In Hong Kong, higher perceived neighbourhood disorder has been found to be negatively associated with new immigrants' quality of life and psychological health (Wong, Chou, & Chow, 2012).

2.2. Urban greenery and subjective well-being

Urban greenery is a complex concept. Scholars and urban planners accept that urban greenery contains a range of parks, street trees, lawns, shrubs, urban agriculture, vertical greenery, and roof gardens (Swanwick, Dunnett, & Woolley, 2003). Contact with greenery has been found to confer health and well-being benefits through immersion or mere "views" (Hartig et al., 2014; Keniger et al., 2013). The close connection between humans and the nature environment can be interpreted from the "biophilia hypothesis", which suggests that human beings have an innately affiliation with nature (Ulrich, 1993). Evidence from existing research has proved that urban greenery is conducive to promoting not only physical and mental health but also social health, as well as subjective well-being (De Vries, Van Dillen, Groenewegen, & Spreeuwenberg, 2013; Fan, Das, & Chen, 2011; Houlden, Weich, Porto de Albuquerque, Jarvis, & Rees, 2018; McCormick, 2017; Nisbet et al., 2011; Twohig-Bennett & Jones, 2018). The underlying mechanism of the positive effect of urban greenery can be summarized in three folds: 1) offering attention restoration and emotional recovery to alleviate stress based on the Attention Restoration Theory (ART) and Stress Recovery Theory (SRT) (Kaplan & Kaplan, 1989; Kaplan, 1995); 2) providing space to facilitate physical activity and social communication; and 3) mitigating environmental hazards such as enhancing thermal comfort, and reducing noise or air pollution (Lachowycz & Jones, 2013; Markevych et al., 2017; Nieuwenhuijsen, Khreis, Triguero-Mas, Gascon, & Dadvand, 2017). Besides, scholars found that urban greenery may enhance the feeling of social safety, yet dense trees and shrubs could be a matter of concern with crime and violence (Groenewegen, Van den Berg, De Vries, & Verheij, 2006; Hong et al., 2018; Lovasi et al., 2013; Maas et al., 2009).

The linkage between urban greenery and subjective well-being has attracted rising attention from urban planning and public health scholars over the last decade. Empirical studies found that the level of subjective well-being, or life satisfaction significantly differed by urban greenery characteristics, including size or proportion, existence, types, accessibility, use and visit (Akpinar, Barbosa-Leiker, & Brooks, 2016; Reyes-Riveros et al., 2021; Wood, Hooper, Foster, & Bull, 2017). Previous studies typically focused on the quantity of overall urban greenery within an area, such as the size of green space, the percentage of green space or vegetation cover, or overall vegetation level (e.g., measured by the normalized difference vegetation index) (Alcock, White, Wheeler, Fleming, & Depledge, 2014; Fan et al., 2011; Liu, Xiao, & Wu, 2022; Yuan, Shin, & Managi, 2018). Several studies found that vegetation level has a positive impact on subjective well-being (Fan et al., 2011; Liu et al., 2022; Triguero-Mas et al., 2015). Researchers also observed significant positive impacts of the amount or proportion of urban green space on restorative quality and well-being (A. Dzhambov, Hartig, Markevych, Tilov, & Dimitrova, 2018; Houlden, Weich, & Jarvis, 2017; Wood et al., 2017). Such a positive effect has also been found in a longitudinal study in the United Kingdom, which observed a mental well-being improvement after moving to a greener neighbourhood (Alcock et al., 2014). Meanwhile, researchers found that the frequency and total time of visiting green spaces are correlated with psychological well-being and life satisfaction (Fleming, Manning, & Ambrey, 2016; Gilchrist, Brown, & Montarzino, 2015; Home, Hunziker, & Bauer, 2012), and increasing access to urban greenery may provide a protective effect for against negative mental components, i.e., anxiety, mental disorder, and suicide mortality (Ekkel & de Vries, 2017; Jiang, Stickley, & Ueda, 2021; Nutsford, Pearson, & Kingham, 2013). In terms of the types of greenery, people who lived in neighbourhoods with more forests, or tree canopy over 30 % may report better mental level, while exposure to over 30 % grass could lead to a higher risk of psychological distress (Akpinar et al., 2016; Astell-Burt & Feng, 2019). Thus, there is convergent evidence from the direct and indirect effects that exposure to urban greenery may provide a "buffer" to cope with stressful life events and neighbourhood deprivation (van den Berg et al., 2010).

2.3. Potential moderation effect of urban greenery

As we discussed above in the Introduction section, the 'equigenesis' theory indicated that people who lived in a low socioeconomic neighbourhood may benefit more from the urban greenery, that is to say, urban greenery may moderate the negative effect of socioeconomic inequalities in health outcomes (Mitchell et al., 2015). Most of the current evidence were focused on European context, while related studies in Asia is rare (Mitchell et al., 2015; Pearce, Mitchell, & Shortt, 2015; Wang, Feng, & Pearce, 2022). Besides, only a few studies had explicitly examined the moderation effect of urban greenery on the relationship between socioeconomic deprivation or social environment and health outcomes. Several scholars noted that the significant restoration impact of urban greenery existed only in a scenario where social connection was absent, such as, the participant was (imaging) alone and without being accompanied by family members or friends (Johansson, Hartig, & Staats, 2011; Staats & Hartig, 2004). A study conducted in the United Kingdom further confirmed that people who reported a high level of nearby greenery might show a high level of subjective well-being even they were with poor social connections (Cartwright et al., 2018). Besides, a study conducted in Sweden showed that people who spent more time contemplating nature and wildlife were less negatively impacted by traumatic events on their mental health (Ottosson & Grahn, 2008). Using national-wide survey data, researchers in the Netherlands found a significant moderation effect of the amount of green space within 3 km on the association between stressful life events and perceived health status (van den Berg et al., 2010). These studies provide evidence that urban greenery may play an important role in mitigating negative feelings caused by neighbourhood deprivation.

2.4. Objective greenery vs Perceived greenery

Existing studies heavily relied on two methods for measuring urban greenery (Dzhambov, Browning, Markevych, Hartig, & Lercher, 2020; Houlden et al., 2018; Yang, Wu, Zhou, Gou, & Lu, 2019). The first one is a subjective method that uses self-reported questionnaires, which ask participants to rate their perception of exposure to urban greenery components, including the distance, size, satisfaction, or report their visiting behaviour (Houlden et al., 2018). The second one is an objective method based on satellite imagery and land-use databases, such as NDVI, percentage or size of green space and tree count within a study area. The advantage of the objective method lies in efficiency, measurable, and quantifiable, as well as avoiding recall bias or social desirability bias (Tsurumi & Managi, 2015). However, most objective measurements are limited to accessing the urban greenery from an overhead view, which is a two-dimensional perspective and failed to capture the most common eye-level view of what people perceived of urban greenery. Some researchers argued that the non-significant or negative association between urban greenery assessed using objective measures and well-being outcomes might be attributable to the neglect of perceived greenery (Villeneuve et al., 2018; Zhang et al., 2019) and the disagreement between perceived greenery and objective greenery measurements (Leslie, Sugiyama, Ierodiaconou, & Kremer, 2010). The emergence of street view images available on Google online map service provides an opportunity to audit the built environment from a human-orientated perspective by stitching a continuous 360-degree image of

a streetscape and has been applied to extract the visible urban greenery with deep learning techniques in urban studies and public health studies recently (Liu et al., 2022; Lu, 2019; Lu, Yang, Sun, & Gou, 2019; Yang, Lu, Yang, Gou, & Zhang, 2020).

2.5. Research gaps

To summarise, most empirical studies support the link between neighbourhood deprivation and subjective well-being, and between urban greenery and subjective well-being. However, little is known about whether the negative effect of neighbourhood deprivation on subjective well-being can be moderated by exposure to urban greenery. Secondly, studies have exclusively focused solely on using either the perceived or objective measure of urban greenery and hence suffered from the respective limitations. Moreover, most studies on urban greenery and subjective well-being were conducted in western societies, which can be characterized by relatively low-density urban environment. Evidence from high-density compact Asian cities remains lacking. As an affluent society with extremely high urban density, high poverty rate and low subjective well-being level, studies on this subject in Hong Kong up to now have been restricted to physical facilities among subgroups, while the effect of the natural environment received less attention (Guo, Chan, Chang, Liu, & Yip, 2019; Guo et al., 2020; Hsu et al., 2017). The effect of urban greenery on subjective well-being in Hong Kong might be different from the western city context, and thus may further inform evidence-based policymaking and environmental recommendations for urban planning implementations in other high-density cities in this region.

To address the abovementioned research gaps, we investigated the moderating role of urban greenery on the impact of neighbourhood deprivation on subjective well-being in Hong Kong, one of the most densely populated cities with approximate 7000 people per square km. To understand the effect of different urban greenery components, we applied three approaches to assess urban greenery, including 1) NDVI, an over-head view indicator derived from remote sensing satellite images; 2) Greenery View Index, an eye-level indicator assessed with Google Street View images; and 3) closeness to nearby parks, a park proximity which extracted from geospatial database. We hypothesise that the negative impact of neighbourhood deprivation on subjective well-being would be moderated by a higher urban greenery level.

3. Method

3.1. Sample

Hong Kong is one of the most densely populated cities with limited developed land in the world. In 2021, the population has reached 7.41 million with a gross population density of 6712 people per square km (Census and Statistics Department, 2021). Given that 75 % of the total land area in Hong Kong is preserved and only 25 % of it has been developed, the population density would be higher in urban built-up areas.

Data for current analyses were extracted from the two-wave Hong Kong Panel Survey for Poverty Alleviation (HKPSPA), which aimed to explore the determinants of poverty in Hong Kong. The panel survey adopted a stratified cluster random sampling method and included separate questionaries for household heads and household members. The first and second wave interviews were conducted face-to-face in 2015 (N = 5922[1]) and in 2017 (N = 2870) to collect participants' demographic data, household information, poverty status, physical and mental health and life experience. The survey was conducted in Chinese and English. We included 1752 household heads who reported their individual information (dwelling location, gender, age, marital and education status, monthly household income and housing type) and have valid records of subjective well-being in 2015. The dwelling locations of each participant were geocoded in ArcGIS based on their reported residential large street block group (LSBG), which is the smallest census track in Hong Kong.

3.2. Neighbourhood deprivation

We measured two dimensions of neighbourhood deprivation discussed in the section 2.1: socioeconomic disadvantage and social environment. For socioeconomic disadvantage, we referred to Messer et al. (2006)'s study including five aspects of socio-economic status: income ((i) household median income), poverty ((ii) percentage of poor household; (iii) percentage of working poor household), education ((iv) percentage of the population with secondary education or below), employment ((v) unemployment rate), housing ((vi) the percentage of households with more than one person per room) and occupation ((vii) percentage of the population with non-professional, non-managerial or non-administrative occupation). For neighbourhood social environment, we focused on social fragmentation. With reference to Bagheri et al., (2019)'s study, we included family structure ((viii) the percentage of single-parent household, (ix) percentage of single-person household, (x) percentage of single-elderly household, (xi) percentage of never-married population, (xii) percentage of divorced/separated population) and residential mobility ((xiii) percentage of non-owner-occupied housing and (xv) percentage of people with residences different from those five years ago). We also included (xiv) percentage of households with new arrivals from mainland China since they are the main source of population growth in Hong Kong (Lloyd et al., 2019). A detailed description could be found in our previous studies (Yeung, Men, Caine, & Yip, 2022).

All the above variables were obtained from the Hong Kong 2016 Population By-census. We performed exploratory principal component analyses (PCA) for socioeconomic disadvantage and social fragmentation, respectively. The components with eigenvalue>1 were extracted, and the factor loading matrices were rotated to obtain the scores for each factor (see Appendix I for the detailed results of PCA). The scores were computed and normalized to create the indices that ranged from 0 (least disadvantaged/fragmented) to 1 (most disadvantaged/fragmented).

3.3. Urban greenery

We used three methods to assess urban greenery conditions, namely the normalized difference vegetation index (NDVI), greenery view index (GVI) and closeness to nearby parks.

3.3.1. Overall greenery

NDVI is one of the most broadly acknowledged objective measurements to quantify the level of overall vegetation greenness in agriculture, forest, and urban studies by using multispectral remote sensing images (Pettorelli, 2013; Rhew, Vander Stoep, Kearney, Smith, & Dunbar, 2011). This indicator is calculated as the difference between near-infrared (NIR) and red (RED) reflectance. Specifically, lands covered with green vegetation reflect more infrared radiation and absorb more energy in the red wavelength compared with non-vegetated surfaces (Pettorelli, 2013). We extracted the NDVI at a 30 m resolution from the United States Geological Survey website, which provides Landsat 8 satellite imagery in its Global Visualization Viewer platform (United States Geological Survey, 2022). The satellite images of 2015 were collected. The formula of NDVI is:

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

[1] Among the 5922 respondents, 2002 were household heads and 3920 were household members. The information on physical and mental health, life experience and subjective well-being were only available for household heads.

The values of NDVI range from −1.0 to1.0, wherein a higher value indicates a higher level of dense vegetation and a lower NDVI value indicates sparse vegetation. The average NDVI value within a census unit where an individual located was used as the proximity of overall greenery in a neighbourhood.

3.3.2. Visible greenery

The visible greenery, indicating the perception of eye-level greenness by pedestrians, was assessed by Google Street View (GSV) images. To collect the GSV images, over 50,000 sample points were generated at a distance of 50 m along with the road network of the whole city. The generation procedure was implemented on the ArcGIS platform to acquire the accurate coordinates of each sampling point. Street view images in eight directions were requested to stitch a panorama at each sampling point with a 120-degree horizontal field of view and covered a 360-degree horizontal circle from four directions, and two vertical angles via the Street View Static API. Over 400,000 street view images were collected in 2020, while over 72 % of the images were taken from May to November in 2019. We did not consider the seasonal fluctuations in current study since Hong Kong is a subtropical city and most of its vegetation are evergreens or semi-evergreens. Besides, the Greening Master Plan for Urban Areas had been completed in 2011. The semantic segmentation with deep learning techniques was applied to develop a script aiming at extracting the vegetation information (i.e., trees, shrubs, and other greenery) from panorama images. Here we applied a pre-trained network generated from the Cambridge-driving Labeled Video Database (CamVid) (Brostow, Fauqueur, & Cipolla, 2009) and the Deeplab v3 + network (Chen, Zhu, Papandreou, Schroff, & Adam, 2018) with weights initialized from a pre-trained Resnet-18 network (Alshehhi & Marpu, 2021). The trained model can achieve an accuracy of 95 % in capturing vegetation. In the current study, we defined a Green View Index (GVI), indicating the visual greenery, as the ratio of visible greenery pixels to total pixels of the panorama images at a sample point, which was expressed as

$$GVI_i = \frac{VegetationPixel_i}{TotalPixel_i}$$

where for the panorama images, $VegetationPixel_i$ denotes the number of pixels of vegetation class, and $TotalPixel_i$ represents the total amount of pixels. The values of GVI range between 0.0 and 1.0, with higher values representing a high level of visible greenery. The average GVI value for all sampling points within the census unit where an individual lived was used to assess the level of visual greenery in his/her neighbourhood.

3.3.3. Park proximity

The park proximity was defined as closeness to nearby parks, which is the shortest distance between urban parks and the centroid of the residential neighbourhood. The location of urban parks was extracted from the GeoCommunity database (iGeoCom) of the Land Department of Hong Kong SAR (Land Department, 2018).

3.4. Outcome

The HKPSPA project adopted the Satisfaction with Life Scale (SWLS) to estimate the individuals' evaluation of their life experiences and personal feeling (Diener, Emmons, Larsen, & Griffin, 1985). The scale has been validated as a valid and reliable measure of subjective well-being for a wide range of age groups (Diener et al., 1985; Pavot, Diener, Colvin, & Sandvik, 1991). The scale consists of five statements, including 1) In most ways my life is close to my ideal; 2) The conditions of my life are excellent; 3) I am satisfied with my life; 4) So far I have gotten the important things I want in life; and 5) If I could live my life over, I would change almost nothing. Participants were asked to rate on a 7-point Likert scale ranging from very disagree (value = 1) to very agree (value = 7). The total score ranges from 5 to 35. The higher the scores, the more satisfied the respondents were with their lives. The Cronbach's alpha is 0.86.

3.5. Covariates

Previous studies provided solid evidence that neighbourhood built environment affects residents' subjective well-being. A high urban density may lead to the feeling of oppressing and crowding, as well as decrease the use of open space and facilities (Cao, 2016; Ho et al., 2008; Perini & Magliocco, 2014). Meanwhile, poor urban connectivity may be detrimental to subjective well-being (Burton, Mitchell, & Stride, 2011; Cao, 2016; Sarkar, Gallacher, & Webster, 2013). In this study, we included three built environment factors within the large street block, including urban density, urban connectivity, and activity-related facilities. Given the high-density, high diversity development in Hong Kong, urban density was assessed by the floor area ratio (FAR), defined as the total floor area of buildings within a neighbourhood divided by the area of such neighbourhood (Caves, 2004). Urban connectivity was measured as the number of street intersections (three or more streets) within the neighbourhood, and activity-related facility was defined as the number of recreation and sports space within the neighbourhood (Handy, Paterson, & Butler, 2003).

Individual-level factors included age, gender, marital status, education level, monthly household income and household type. The age was transformed into a 3-band categorical variable (18–44 years – reference group; 45–64 years; and above 65 years). The marital status was converted into a 3-band categorical variable (single – reference group; married/ cohabiting; and divorced/separated/widowed) The education level was transformed into a 3-band categorical variable (primary school or below - reference group; secondary school, and university). The monthly household income was categorized as HKD < 10,000, 10,000 – 13,999, 14,000 – 19,999, 20,000 – 31,999, or > 32,000. The housing type was categorized as homeowners, public tenants and private tenants.

3.6. Data analysis

Multilevel linear regression models were used to examine the independent association of urban greenery with the level of subjective well-being. Individual participants (level 1) were modelled to be clustered within neighbourhoods (level 2, LSBG) with random intercepts. We first run Model 0, a null model with intercept only to estimate the between-group effects with intraclass correlation coefficient. Second, we investigated the direct relationship between single urban greenery measurements, neighbourhood deprivation indices and subjective well-being after adjusting for built environment factors and individual covariates (Model 1, 2 and 3). Third, to look into the relative importance of different urban greenery components, we also run models by adding multiple urban greenery measurements in the same model. Due to the high correlation between NDVI and GVI, we included NDVI and closeness to nearby parks in Model 4, and GVI and closeness to nearby parks in Model 5 respectively. The multilevel model used for analysis was as follows:

$$Y_{ij} = \gamma_0 + \beta^{*}Greenery_j + \gamma_1{}^{*}Neighbourhood_j + \gamma_2{}^{*}Covariate_{ij} + \mu_j + \tau_{ij}$$

where Y_{ij} denotes the subjective well-being score of individual i lived in the neighbourhood j. $Greeenry_j$ denotes the urban greenery level of neighbourhood j and β denotes the coefficient of urban greenery on subjective well-being; $Neighborhood_j$ denotes the variables of neighbourhood j, $Covariate_{ij}$ denotes the personal covariates of individual i lived in the neighbourhood j, and γ_1, γ_2 were their coefficients, respectively. μ_j and τ_{ij} denotes the random residual in neighbourhood level and individual level, respectively.

Last, we further conducted a moderation analysis to investigate whether the negative effect of neighbourhood deprivation on subjective

well-being, if any, was moderated by urban greenery. The impact of moderator variables may modify the strength of the effect of an independent variable on the dependent variable. In the present study, the moderation analysis was examined as an interaction effect between neighbourhood deprivation and urban greenery. If a significant moderation effect of certain type of urban greenery could be observed, we believe that a higher level of urban greenery may contribute to mitigating (buffering) the negative effect of neighbourhood deprivation on residents' subjective well-being.

All the analyses were performed using statistical software STATA 14.0. Coefficient (β), 95 % confidence intervals (CI), and p-value were reported for the models. A flowchart of research step was shown in Fig. 1.

4. Results

4.1. Descriptive statistics

Descriptive statistics of the study samples are shown in Table 1. Females accounted for 51.94 % of the sample and had higher subjective well-being scores than males (22.16 vs 21.40). Older adults (65 years or above) comprised only 25.29 % of all participants but had the highest subjective well-being scores of 23.72 among all age groups. Most of the participants were currently married or cohabiting, with secondary education level, and living in public or private rental housing. The highest income group (32,000 and above HKD/month) comprised over one-quarter of the total participants (25.11 %) and had the highest subjective well-being score (24.34), while the second-lowest income group (10,000–13,999 HKD/month) comprised 11.53 % of total participants and had the lowest subjective well-being score (19.99).

The descriptive statistics of neighbourhood socioeconomic and built environment characteristics are shown in Table 2. The average socioeconomic disadvantage across all sample neighbourhoods was rather high (0.63), while the average social fragmentation was 0.26. The average values of the Greenery View Index assessed by Google Street View Images were 0.20, while the average values of NDVI derived by satellite remote sensing images were 0.16. The average values of distance to the nearest park were 0.16. The GVI and NDVI values were strongly correlated (Pearson correlation r = 0.756), while the GVI and park proximity values and NDVI and park proximity values were small to moderate correlated (Pearson correlation r = 0.349 and 0.545, respectively).

Table 1
Descriptive statistics of the study samples (N = 1752, Hong Kong SAR).

	Count	Percentage	Subjective Well-being Score	Chi square test/*t* test
	N	%	MEAN (SD)	
Gender				0.035
Male	842	48.06	21.40 (7.28)	
Female	910	51.94	22.16 (7.59)	
Age Group				107.52**
18–44	588	33.56	20.67 (7.41)	
45–64	721	41.15	21.53 (7.57)	
>65	443	25.29	23.72 (6.93)	
Marital status				96.17**
Single	409	23.35	20.49 (7.23)	
Married/cohabiting	1064	60.73	22.64 (7.32)	
Divorced/separated/ widowed	279	15.93	20.48 (7.80)	
Education status				83.31*
Primary school and below	402	22.95	22.96 (7.20)	
Secondary School	961	54.85	21.10 (7.58)	
University and above	388	22.15	22.29 (7.18)	
Monthly household income (HK dollars)				196.21**
0–9999	471	26.88	20.50 (7.44)	
10000–13999	202	11.53	19.99 (7.92)	
14000–19999	207	11.82	20.37 (7.29)	
20000–31999	432	24.66	22.13 (7.06)	
>32000	440	25.11	24.34 (6.96)	
Housing type				145.23**
Homeowners	667	38.07	23.89 (6.92)	
Public tenants	906	51.71	20.34 (7.33)	
Private tenants	179	10.22	21.36 (8.12)	
Total			21.79 (7.45)	

*p < 0.05, **p < 0.01, ***p < 0.001.

4.2. Multilevel linear regression models result

Table 3 presents the results of three multilevel linear regression models for predicting the subjective well-being scores at the LSBG level with different urban greenery indicators. The result from null model

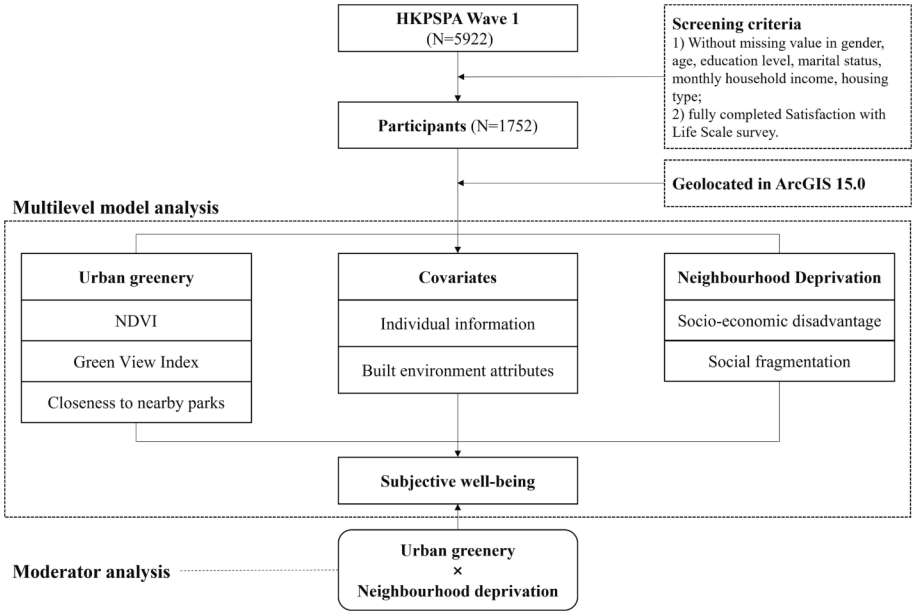

Fig. 1. Research step in current study.

Table 2
Descriptive statistics of the neighbourhood level variables.

	Large Street Block Group (N = 256)
	MEAN (SD)
Neighbourhood deprivation	
Socio-economic disadvantage	0.63 (0.14)
Social fragmentation	0.26 (0.13)
Built Environment	
Urban Greenery	
GVI	0.20 (0.14)
NDVI	0.16 (0.14)
Closeness to nearby park (km)	0.16 (0.21)
Urban Density	
FAR	2.99 (2.21)
Urban connectivity	
Number of street intersection	14.08 (26.18)
Activity related facility	
Number of recreation and sports space	4.20 (5.30)

suggested that 7.8 % of the total individual difference in subjective well-being occurred at the LSBG level ($ICC_{LSBG} = 0.078$), thus it is reliable to apply a multilevel model rather than a single level model.

After controlling for built environment factors and individual covariates, we found that social fragmentation had a negative association with subjective well-being across all models with single urban greenery measures (in Model 1: $\beta = -1.73$, $p < 0.05$;p Model 2: $\beta = -1.72$, $p < 0.05$; Model 3: $\beta = -2.58$, $p < 0.05$), suggesting that people who lived in a neighbourhood with less connection between individual and society reported a lower subjective well-being level. Two urban greenery indicators – GVI ($\beta = 4.68$, $p < 0.01$) and NDVI ($\beta = 3.83$, $p < 0.05$), were significantly and positively associated with subjective well-being. Compared with those who lived in a neighbourhood with lower visible greenery or overall greenery, participants who lived in a neighbourhood with higher visible or overall greenery reported higher subjective well-being level. We did not observe any significant association between subjective well-being and closeness to nearby parks and other built environment factors.

Among the individual covariates, female participants are likely to have higher subjective well-being than male participants. The middle-aged adults (45–64 years) and older adults (65 years or above) had higher subjective well-being compared with youth adults (18–44 years). As expected, house owners had higher subjective well-being compared with tenants, while household monthly income level was positively associated with subjective well-being. In addition, higher education level was negatively associated with subjective well-being, and marital status was not significantly associated with subjective well-being level.

Model 4 and 5 in Table 4 show that visible greenery assessed by GVI ($\beta = 5.44$, $p < 0.05$) and overall greenery assessed by NDVI ($\beta = 4.69$, $p < 0.05$) were positively related to the subjective well-being. On the contrary, closeness to nearby parks was not significantly associated with subjective well-being in any models, which was consistent with results shown in Table 3.

4.3. Moderation effect

Table 5 and Fig. 2 demonstrates the moderation effect of different urban greenery indicators on the relationship between social fragmentation and subjective well-being level. After adjusting for the socioeconomic factors, built environment factors and individual covariates, we found a significant moderation effect of visible urban greenery between social fragmentation and subjective well-being, suggesting that a higher level of visible greenery may mitigate the negative impact of social fragmentation on subjective well-being. No significant moderation effect of NDVI or the park proximity between social fragmentation and subjective well-being was observed.

Table 3
Multilevel linear regression results of adjusted models for predicting the individual subjective well-being (N = 1752, single urban greenery measurement).

Model predictor	Model 1	Model 2	Model 3
	GVI	NDVI	Closeness to nearby park
	β, (95 % CI)	β, (95 % CI)	β, (95 % CI)
Intercept	19.43*** (16.89, 21.97)	19.44*** (16.84, 22.04)	20.48*** (18.02, 22.95)
Neighbourhood deprivation			
Socio-economic disadvantage	−0.94 (−5.69, 3.81)	−0.21 (−3.79, 3.38)	−0.01 (−3.66, 3.65)
Social fragmentation	−1.73* (−5.82, 2.35)	−1.72* (−5.80, 2.35)	−2.58* (−6.66, 1.51)
Built Environment			
Greenery	4.68** (0.74, 8.63)	3.83* (0.21, 7.46)	0.33 (−1.85, 2.50)
FAR	0.12 (−0.06,0.30)	0.17 (−0.03,0.38)	0.05 (−0.14,0.23)
Connectivity	0.01 (−0.01, 0.02)	0.01 (−0.01, 0.02)	0.01 (−0.01, 0.02)
Sports Space	0.07 (0.01, 0.14)	0.07 (0.01, 0.14)	0.06 (0.02, 0.13)
Individual			
Gender			
Male [reference]			
Female	1.25** (0.60, 1.91)	1.23*** (0.57, 1.89)	1.21*** (0.55, 1.88)
Age			
25–44 [reference]			
45–64	0.90* (0.04, 1.75)	0.82* (0.04, 1.67)	0.87* (0.01, 1.72)
65 and above	4.17*** (3.06, 5.29)	4.07*** (2.95, 5.18)	4.10*** (2.99, 5.22)
Marital status			
Single [reference]			
Married or cohabiting	0.45 (−0.43, 1.33)	0.47 (−0.42, 1.67)	0.47 (−0.41, 1.35)
Divorced/ separated/ widowed	−0.96 (−2.17, 1.75)	−0.94 (−2.11, 0.24)	−0.97 (−2.15, 0.20)
Education Status			
Primary or below [reference]			
Secondary	−1.56** (−2.46, −0.66)	−1.60** (−2.49–0.69)	−1.58** (−2.48, −0.68)
University	−1.55** (−2.76, −0.35)	−1.63** (−2.83, −0.42)	−1.57* (−2.78, −0.36)
Monthly household income			
Lowest −9,999 [reference]			
10,000–13,999	0.74 (−0.42, 1.91)	0.74 (−0.42, 1.91)	0.69 (−0.48, 1.86)
14,000–19,999	1.35* (0.16, 2.55)	1.34* (0.15, 2.54)	1.30* (0.10, 2.50)
20,000–31,999	3.22*** (2.22, 4.22)	3.23*** (2.22, 4.23)	3.17*** (2.17, 4.18)
32,000-highest	4.96*** (3.87, 6.04)	4.97*** (3.89, 6.06)	4.94*** (3.85, 6.03)
House type			
Homeowners [reference]			
Public tenants	−1.91*** (−2.73, −1.10)	−1.88*** (−2.70, −1.06)	−1.96*** (−2.80, −1.13)
Private tenants	−1.59** (−2.76, −0.42)	−1.63** (−2.80, −0.48)	−1.62** (−2.79, −0.44)
ICC (LSBG)	0.019	0.018	0.19
Random effect			
Var (LSBG)	0.91*	0.86*	0.92*

Note: *p < 0.05, **p < 0.01, ***p < 0.001.
ICC: Intraclass correlation coefficients.
LSBG: Large street block group.

Table 4
Multilevel linear regression results of adjusted models for predicting the individual subjective well-being (N = 1752, multiple urban greenery measurements.).

Model predictor	Model 4	Model 5
	GVI + Closeness to nearby park	NDVI + Closeness to nearby park
	β, (95 % CI)	β, (95 % CI)
Intercept	19.42*** (16.86, 21.97)	19.39*** (16.79, 22.00)
Neighbourhood deprivation		
Social deprivation	−0.74 (−4.33, 2.85)	−0.25 (−3.84, 3.35)
Social fragmentation	−1.52 (−5.66, 2.62)	−1.39 (−5.54, 2.75)
Built Environment		
GVI	5.44* (1.25, 9.63)	
NDVI		4.69* (0.54, 8.83)
Closeness to nearby park	−0.68 (−3.26, 1.89)	−1.08 (−3.68, 1.52)
FAR	0.12 (−0.06, 0.31)	0.18 (−0.03, 0.39)
Connectivity	0.01 (−0.01, 0.02)	0.01 (−0.01, 0.02)
Sports Space	0.07 (0.01, 0.14)	0.08 (0.01, 0.15)
Individual		
Gender		
Male [reference]		
Female	1.25*** (0.59, 1.91)	1.24*** (0.57, 1.90)
Age		
25–44 [reference]		
45–64	0.89* (0.03, 1.74)	0.82 (−0.03, 1.68)
65 and above	4.16*** (3.05, 5.28)	4.07*** (2.96, 5.18)
Marital status		
Single [reference]		
Married or cohabiting	0.44 (−0.44, 1.32)	0.49 (−0.39, 1.37)
Divorced/ separated/ widowed	−1.00 (−2.17, 0.17)	−0.93 (−2.10, 0.24)
Education Status		
Primary or below [reference]		
Secondary	−1.58** (−2.48, −0.68)	−1.57** (−2.47, −0.67)
University	−1.55* (−2.76, −0.35)	−1.60** (−2.80, −0.39)
Monthly household income		
Lowest −9,999 [reference]		
10,000–13,999	0.76 (−0.40, 1.93)	0.74 (−0.42, 1.91)
14,000–19,999	1.39* (0.20, 2.59)	1.34* (0.148, 2.54)
20,000–31,999	3.23*** (2.23, 4.23)	3.23*** (2.23, 4.24)
32,000-highest	4.97*** (3.88, 6.05)	4.96*** (3.88, 6.05)
House type		
Homeowners [reference]		
Public tenants	−1.90*** (−2.72, −1.08)	−1.91*** (−2.74, −1.09)
Private tenants	−1.60** (−2.77, −0.43)	−1.67** (−2.84, −0.50)
ICC	0.019	0.018
Random effect		
Var (LSBG)	0.75*	0.86*

Note: *p < 0.05, **p < 0.01, ***p < 0.001.
ICC: Intraclass correlation coefficients.
LSBG: Large street block group.

5. Discussion

In this study, we investigated the association between neighbourhood deprivation, urban greenery, and subjective well-being using population-based data from 1,752 individuals in Hong Kong in 2015. We adopted three different measures of urban greenery to get a comprehensive understanding of the relationship between urban greenery, neighbourhood deprivation, and subjective well-being, including the overall vegetation level- NDVI derived from satellite images, the visible greenery- GVI extracted from street view images, and the park proximity- distance to the nearest park. We further conducted a moderation effect analysis to examine the buffering of urban greenery on the negative impact of social fragmentation on subjective well-being. We found that both visible urban greenery and overall greenery were positively associated with subjective well-being. Results from our study also revealed that neighbourhood-level social fragmentation had a direct negative effect on subjective well-being, and such effect could be mitigated by higher visible greenery.

Table 5
Moderation effect of urban greenery on the relationship between social fragmentation and subjective well-being.

	Estimate	p-value
Moderation Model 1		
GVI	7.13	0.049*
Fragmentation	−10.26	0.003**
GVI × Fragmentation	44.09	0.002**
Moderation Model 2		
NDVI	3.49	0.294
Fragmentation	−1.52	0.019*
NDVI × Fragmentation	13.22	0.305
Moderation Model 3		
Closeness to nearby park	5.77	0.341
Fragmentation	−6.98	0.213
Park Proximity × Fragmentation	25.45	0.091

Note: *p < 0.05, **p < 0.01, ***p < 0.001.
ICC: Intraclass correlation coefficients.
LSBG: Large street block group.

5.1. Neighbourhood deprivation and subjective well-being

Among two neighbourhood deprivation indices, only the social fragmentation was inversely associated with subjective well-being in Hong Kong adults. The association remained when built environment variables and individual covariates were included in the models successively, suggesting that people living in neighbourhoods with weaker social cohesion and integration, for example, a larger proportion of people who live alone or were newly arrived, were less satisfied with their lives. Our findings echo with the evidence in the western city context that a socioeconomic disadvantage arms subjective well-being (Laurence, 2019; Shields, Wheatley Price, & Wooden, 2009). However, it is important to note that two components of social fragmentation, the percentage of migrants and the percentage of homeowners, were non-significantly associated with life satisfaction in a recent study conducted in Beijing (Ma, Dong, Chen, & Zhang, 2018). One of the plausible reasons can be attributed to the difference in social fragmentation between Hong Kong and Beijing, while there was a relatively high proportion of the migrant population and relative low homeowners in Hong Kong. Besides, in comparison with using an independent variable in Ma et al., (2018), our study operationalized social fragmentation in a better way by constructing a composite index rather than a single variable.

5.2. Urban greenery on subjective well-being

We found that both the overall greenery (NDVI) and visible greenery (GVI) were positively associated with subjective well-being. The positive effect of NDVI was consistent with existing studies revealing the importance and benefit of dense and leaful vegetation cover within the neighbourhood on subjective well-being (Liu, Xiao, Liu, Yao, & Wang, 2021; Wang et al., 2019). Our findings suggest that the visual contact with street greenness also provides a direct beneficial effect on subjective well-being, supporting the argument that visible greenery was as important as the overall greenery. Surprisingly, no significant association was found between subjective well-being and park proximity, which is in contrast with previous studies in the western context (Ayala-Azcárraga, Diaz, & Zambrano, 2019; Bertram & Rehdanz, 2015; Grilli, Mohan, & Curtis, 2020). Given that participants in the current study

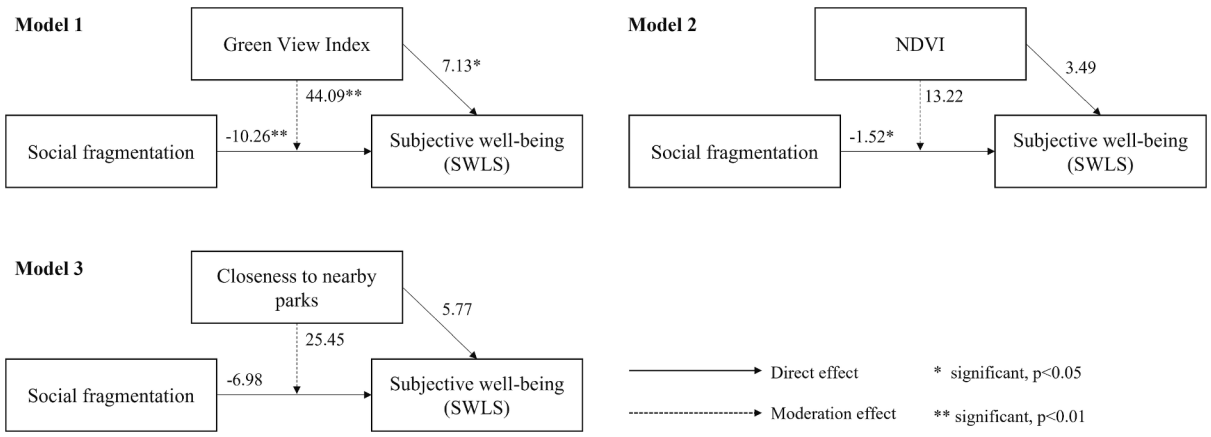

Fig. 2. The statistical diagram of moderation effect of urban greenery on the relationship between social fragmentation and subjective well-being.

were recruited by stratified cluster sampling method and focused on a key population of poverty characteristics, it is plausible that the lack of significance of park proximity in this study may be due to low-income people having to endure long working hours to cover daily living expenditure and therefore being less likely to spend time visiting parks. This suggests that street green is a substitute for park green in low-income neighbourhoods. We do not know of other studies testing or yielding this hypothesis, though there are studies showing that one type of green substitutes for another (e.g., private for public greenery, and club-community green for municipal greenery (Woo & Webster, 2014)). Besides, the distance between neighbourhoods and nearby parks is relative short in Hong Kong. In current study, 241 of 256 neighbourhoods can reach community parks within a 400 m buffer, thus may weaken the disparities in accessing parks and the effect of park proximity on subjective well-being among the sample participants.

We then examined the moderation effect of urban greenery on the linkage between neighbourhood deprivation and subjective well-being, and observed a significant buffering of visible greenery as our suggested conceptual model. As we discussed in the beginning, the visual contact with greenery has positive association with reductions in stress, specifically in current study, to response to the stress of lack of social cohesion and integration. Evidence from our study reveals the potential of visible greenery to affect socioeconomic inequality on individual well-being level and corroborates the findings of a previous study in the UK. Mitchell and Popham (2008) noted that the linkage between income deprivation and mortality significantly differed by the exposure to urban greenery and emphasized the crucial role of greenery against socio-economic inequality and health equality.

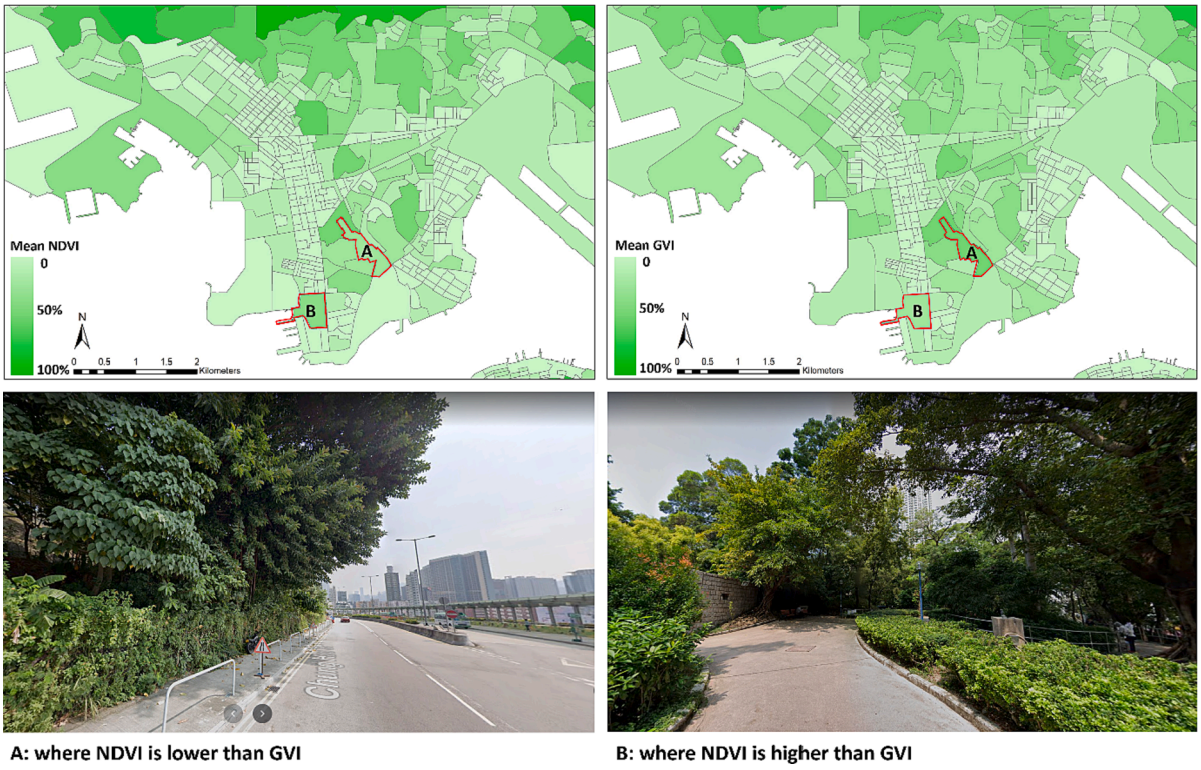

Fig. 3. The overall greenery assessed by NDVI, and visible greenery assessed by GVI by Large Street Block Group unit in Kowloon, Hong Kong. Visible greenery is higher than overall greenery in Area A (ranging 40%-50% in GVI and 20%-30% in NDVI), a neighbourhood with well-maintained and multilevel designed street greenery. Visible greenery is lower than overall greenery in Area B (ranged 20%-30% in GVI and 30%-40% in NDVI), such as parks (Kowloon Park in this figure) and preserved areas.

The urban greenery measurements applied in our study capture different dimensions of urban greenery, while the NDVI focuses on the surrounding vegetation level, GVI focuses on the visible street greenery at the eye level, and closeness to parks focuses on the accessibility to urban green facilities. Besides, the overall greenery mismatched the visible greenery in Hong Kong. For example, overall greenery tends to be high in the area with abundant country parks and preserved natural area, and visible greenery tends to be high in neighbourhoods with well-maintained and multilevel designed street greenery (Fig. 3). We believe that in a high-rise, high-density city, exposure to visible greenery at street eye-level better estimates what residents perceive and experience in their routine activity space and thus, has a more significant role in enhancing subjective well-being and moderating the negative effect of social fragmentation rather than overall (obscured) greenery and closeness to nearby parks. We note, by corollary, that in many low-density, low-rise cities, urban parks can be seen from further away.

5.3. Planning implementation into healthy city development

By adding the knowledge of the interaction effect between neighbourhood deprivation and built environment and introducing multi-dimensional measurements of urban greenery, the current study demonstrated the significance of urban greenery, especially visible greenery, in improving subjective well-being and mental health from the neighbourhood deprivation in Hong Kong adults. Findings from our study provide new insights into improving the neighbourhood environment and policymaking to enhance subjective well-being. First, to create a healthy and satisfying society, urban planners need to pay more attention to the residents' perception of urban greenery, more specifically, the exposure to visible greenery. As the community parks and rest gardens in Hong Kong are well-planned and easy to access, more street-line trees and shrubs should be planted in deprived neighbourhood. Given Hong Kong's 'subtropical climate with long hot summers', trees along streets may not only provide a public and contactable greenery source, but also a pleasant and comfortable walking experience. It should be noted that subjective well-being is determined by various factors, and intervention in visible greenery may not bring an immediate improvement on the individual subjective well-being level, but its impact should not be neglected in urban planning practice. Street greenery may provide a protective restoration and positive emotional effects as daily visual contact with urban greenery. Second, we recommend adopting visible greenery into the urban greenery evaluation system as a vertical dimensional indicator rather than exclusively using the overhead view ones such as greenery rate or size of green space. The Green and Blue Space Conceptual Framework in Hong Kong 2030 + suggested that new green index combing multiple elements and three-dimensional design principle should be developed (HKGSAR, 2021). Evidence from our study could contribute to the need of understanding the effect of different urban greenery components and generate fresh insight into planning recommendations for future greening standards, which is as well as suitable for other high-density Asian cities such as Shanghai, Singapore and Tokyo. Third, urban planners and local governments should be keenly aware of the voice, opinions and needs of vulnerable groups since their activity patterns and preferences may differ from other demographic groups. We note that at various times in the development of the long-established cities around the world, street-tree planting has varied as a practice. At times of strong civic movements, such as the early twentieth century throughout Europe and its colonies, routine planting of tree-lined boulevards has bequeathed contemporary cities with mature street-level greenness in their classical pre-war quarters. More laissez-faire periods of urban expansion tend to leave green planting to private investment and private space. Our research adds to a growing body of evidence suggesting that publicly-visible green for all is an investment in the health of city dwellers for many decades to come.

5.4. Study limitations

One of the strengths of the current study is that we assessed urban greenery with three approaches simultaneously, which allows us to explore which kind of aspects of urban greenery was important for subjective well-being. The second strength is that we explored the moderation effect of urban greenery on the association between the neighbourhood deprivation and subjective well-being, thus helping us to understand the complex relationship between neighbourhood deprivation, urban greenery, and individual subjective well-being.

The study also has some limitations. First, we could not reveal the causal inference and avoid the self-selection bias due to the cross-sectional study design in the current study. For example, high-income people could enjoy private and garden-like green space within their housing estates, yet low-income people who lived in public rental housing or single mansion might be monotonous due to the lack of greenery in their estates. Further study may adopt the full panel survey data and natural experimental study design to deliver more robust scientific evidence. Second, the measurement of subjective well-being in the current study only included one aspect referring to subjective well-being. Future studies should include an analysis of the positive affect (PA) and negative affect (NA) to enrich the understanding of subjective well-being. Third, we only included the basic demographic characteristics of participants in analysis model, while subjective well-being was significantly associated with physical and psychological health status. Future studies should also measure physical and psychological health simultaneously. Fourth, as the historical data of Google Street View images are still not available to request via API, we were not able to obtain the visible greenery in a corresponding period with the survey data. In addition, we were not able to measure the spatial autocorrelation in current study, future studies should include such concern to better understand spatial relationship among built environment variables, socioeconomic variables, and subjective well-being.

6. Conclusion

In this study, we based a panel survey database to examine the complex relationship among urban greenery, neighbourhood deprivation, and subjective well-being among adults in Hong Kong. Multilevel linear regression model indicates that subjective well-being was positively associated with both overall greenery and visible greenery. We also found that a higher social fragmentation level would decrease the subjective well-being level. Moreover, one of the most significant findings to emerge from our study is that visible greenery could mitigate the negative effect of social fragmentation on subjective well-being. This evidence has shed new light on our understanding of the interaction between neighbourhood deprivation and nature environment on individual well-being.

Findings from our study have significant implementation for developing healthy city that supports citizens to generate positive emotion and recover from neighbourhood socioeconomic disadvantages, as well as highlight the importance of visible greenery in a high-density urban context. Urban planners and policymakers should consider adopting multidimensional urban greenery measurements and pay special attention to vulnerable groups in future practice.

CRediT authorship contribution statement

Yiyang Yang: Conceptualization, Formal analysis, Methodology, Visualization, Writing – original draft. **Chenhong Peng:** Investigation, Methodology, Writing – original draft. **Cheuk Yui Yeung:** Software, Writing – original draft. **Chao Ren:** Conceptualization, Funding acquisition, Project administration, Supervision, Writing – review & editing. **Hao Luo:** Methodology, Writing – review & editing. **Yi Lu:** Writing – review & editing. **Paul S.F. Yip:** Conceptualization, Investigation, Writing – review & editing. **Chris Webster:** Writing – review & editing.

Declaration of Competing Interest

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.

Data availability

Data will be made available on request.

Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104660.

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