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# The Impacts of Visible Green Spaces on the Mental well-being of University Students

**Yihang Bai[1,6] · Ruoyu Wang[2] · Linchuan Yang[3] · Yantao Ling[4] · Mengqiu Cao[5]**

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## Abstract

The benefits of green spaces on individuals' health have been widely acknowledged due to their inherent natural qualities. Currently, university students are experiencing significantly higher levels of mental health problems than other social groups. There is a scarcity of studies examining the association between built environment factors and mental health issues among university students, particularly in the Chinese context. University campuses in China are physically isolated, secluded communities, and in this respect, they differ markedly from the spatial organisation patterns of Western universities. Therefore, this study focuses on the correlation between the extent of green space exposure within closed university campuses and the occurrence of mental health issues among resident students. A deep-learning methodology incorporating streetscape images, remote sensing data, and multilevel linear modelling is employed in order to facilitate a comprehensive analysis. The results demonstrate a negative correlation between green space exposure on campus and the level of mental health issues among university students. Individual socio-demographic characteristics, such as whether a person has a partner, are also found to influence the level of mental health issues that they experience. In addition, a significant relationship is found between travel patterns and mental health issues, with students who walked regularly having a lower incidence of mental health issues than those who drove. Our research indicates that, in order to foster healthier communities and enhance social inclusion, urban planners should prioritise the development of greener campuses and urban transport services to improve accessibility to green spaces.

## Highlights

- This study investigates the impacts of campus green space exposure on mental health issues.
- The study participants comprised 811 students from 10 universities in Guangzhou, China.

Extended author information available on the last page of the article

- An inverse correlation exists between exposure to green space within closed university campuses and the prevalence of mental health issues.
- Personal characteristics and travel patterns have significant impacts on mental health.

**Keywords** Visible Green Spaces · Mental Health · Public Health · Urban Planning · Travel Behaviour · deep Learning · well-being

## Introduction

The benefits of urban greenery for health and well-being have been widely acknowledged and effectively incorporated into the domains of public health, urban planning, and design (Tokhmehchian & Gharehbaglou, 2019; Barton et al., 2015). A multitude of empirical investigations have demonstrated that exposure to natural green spaces positively influences people's mental health and well-being (De Bell et al., 2017; Dzhambov et al., 2018; Hartig et al., 2014; Wang et al., 2019a; Yang et al., 2020, 2021; Yang, 2007). The World Health Organisation has highlighted the significant benefits of green space for the mental well-being of individuals (WHO, 2016). For example, according to the WHO (2010), active participation in physical activities within green environments has been found to mitigate depression and stress levels. Similarly, the presence of plants or other natural elements within a community can diminish stress and restore people's spirits. A study by Van den Bosch and Meyer-Lindenberg (2019) investigated the relationship between outdoor green space and depression, and recognised the pivotal role that the former plays in influencing individuals' mental health status. However, despite some studies claiming that increased exposure to green spaces mitigates mental health issues (Banay et al., 2019; Helbich et al., 2018; Hystad et al., 2019; Liu et al., 2021), this association has not been universally accepted (Boers et al., 2018; Taylor et al., 2018). De Vries et al. (2013) argued that the health benefits of green spaces may be mediated through factors such as social cohesion. Furthermore, the stable connection between green space exposure and mental health may exhibit more variability in diverse social cohorts, for example, older adults, adolescents, and students (Feng et al., 2022; Wang et al., 2019b).

The mental well-being of students has become an increasing concern in recent studies (Brown, 2016). Numerous studies have provided evidence indicating that an estimated 30–50% of university students worldwide experience at least one potential problem with mental health during their university career (Auerbach et al., 2018; Eisenberg et al., 2011; Said et al., 2013). A recent investigation of 11,954 Chinese university students showed that nearly a third (31.1%) of the participants met the diagnostic criteria for mental health issues (Yang et al., 2019). Furthermore, university students are deemed to be at a heightened risk of experiencing mental health issues compared to other demographic cohorts, although there is still no consensus as to why this is the case, which suggests a need for further research on the subject (Cvetkovski et al., 2012). A literature review examined 24 studies conducted from 1990 to 2010 and revealed that the average occurrence of depression among undergraduate students was 30.6%, a significantly elevated prevalence compared to the

9% prevalence observed within the population of the US as a whole (Ibrahim et al., 2013). Many studies have confirmed the benefits of having green spaces nearby on the mental health of students within educational settings (Collins et al., 2022; Kelz et al., 2015; Liu et al., 2022b). A study of 94 high school students in the US showed that being able to look out onto outdoor green spaces can mitigate stress (Li & Sullivan, 2016). Another study involving 120 students showed that students' mental health was better in a natural outdoor setting than in an indoor environment (Greenwood & Gatersleben, 2016). However, most studies have examined the relationship between neighbourhood greenery or greenery within or near university or college campuses/premises and mental health. According to our literature review, few previous studies have focused on individuals who live in closed environments, and whose exposure to green space encompasses both residential and work/study areas. Consequently, the primary objective of this study is to investigate the relationship between green space within university campuses and the mental health issues of students residing on those campuses.

In China, the majority of university campuses can be characterised as self-contained enclaves, demarcated by perimeter walls and entrance gates, effectively segregating them from the adjacent urban living environment (Sun et al., 2018). To date, most Chinese universities have been structured and managed by the government departments responsible for providing most of the funding for their operation, including accommodation and other essential resources and amenities (Liu, 2017). This governance model has had the effect of making Chinese universities spatially autonomous from other entities, thus suggesting that Chinese university students might have a comparatively higher susceptibility to mental health issues. However, despite extensive research exploring the link between students' mental well-being and built environment factors (see Dzhambov et al., 2021; Gorriz et al., 2022), few studies have attempted to investigate the mental health of university students residing on closed campuses, specifically those in China. Therefore, this research focuses on the environmental determinants present within closed campuses that influence the mental health and well-being of Chinese university students, and aims to establish a theoretical framework for mental healthcare interventions and associated measures that can be tailored to specific local contexts.

To date, a definitive consensus on the connection between green space and mental health and well-being has yet to be established. Several studies have found no statistically significant association between them (Boers et al., 2018; Gascon et al., 2017). This could be attributed to variations in the methodologies employed to quantify and assess exposure to green spaces. Green spaces are often assessed by remote satellite images, which involve quantifying the extent of the vegetation canopy present within a specific geographical region (Markevych et al., 2017; Mitchell et al., 2011; Huete et al., 2010). However, remote sensing measurements are limited in their ability to capture people's daily exposure to green space (Lu, 2019; Ye et al., 2019) and, importantly, they ignore the vertical dimension of urban greenery. Many scholars have questioned whether satellite-based measurements can accurately assess green space exposure as perceived by people at ground level (Helbich et al., 2019; Li et al., 2018). Advancements in the field of computer science have facilitated improvements in the efficiency and accuracy of evaluating green spaces using streetscape images,

in contrast to remote sensing data (Bai et al., 2022). Consequently, this approach has emerged as a viable and pragmatic substitute, which has been widely used in recent research (Liu et al., 2020; Rzotkiewicz et al., 2018). Digital map providers (e.g., Baidu Maps and Google Maps) can display neighbourhood-level street images online. Moreover, recent advancements in deep learning techniques have facilitated the automated recognition of elements of vegetation, such as trees and grass (Long et al., 2015; Yao et al., 2019). As a result, using deep learning technology to assess urban green spaces via street-view images offers a more comprehensive perspective than using remote sensing images. The quality of urban greenery can be enhanced using street-view images as they can show environmental conditions more accurately (Wu et al., 2022), while the quantity of urban greenery can be assessed by remote sensing data which can provide a 360-degree perspective of the area (Gonzales-Inca et al., 2022; Wang et al., 2019d). Therefore, we integrated streetscape images and remote-sensing data to comprehensively evaluate the quality and quantity of green space within the street environment on university campuses, thereby addressing the inherent limitations in terms of reliability associated with remotely sensed images.

In order to fill these research gaps and overcome the aforementioned limitations, this study focuses on the association between campus green space and mental health issues among university students by employing a comprehensive approach that encompasses remote sensing data, streetscape images, deep learning techniques, and multilevel linear modelling. The study population was nested in ten universities within the Guangzhou Higher Education Mega Centre (HEMC), which is characterised by a high density of university campuses. This study offers two main contributions. Firstly, it employs deep learning techniques and remote sensing data to quantify the green spaces within university campuses. This comprehensive approach facilitates the evaluation of both the quality and quantity of green space. Secondly, it links the mental health and well-being of university students on closed campuses with green space, complementing the findings of previous research studies. We focus on the impact of enclosed living environments on the association between green space and the mental health and well-being of university students. Thus, we believe that this study can add to the findings of previous studies and further advance the development of knowledge about the relationship between urban greenery and mental health, as well as improving the health and well-being of individuals.

## Case Study, Data and Methodology

### Research area

Guangzhou HEMC, situated in southern China, encompasses a substantial population comprising more than 250,000 students and teaching personnel (Hu et al., 2012). Guangzhou HEMC is located in the Panyu district of downtown Guangzhou which is well-served by public transport services (Fig. 1). Guangzhou HEMC consists of a very densely distributed group of universities, with many facilities on the island designated almost exclusively for the benefit of the university students and staff. As most of the trees and vegetation in Guangzhou are evergreen or semi-evergreen, this

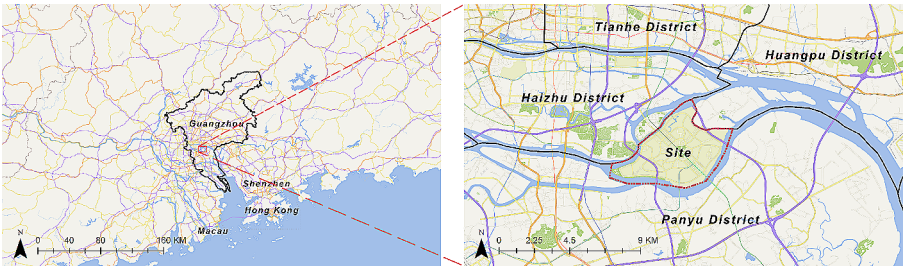


**Fig. 1** The location of Guangzhou HEMC

enabled the problem of seasonal colour changes to be avoided. Given its distinctive demographic context and spatial arrangement, Guangzhou HEMC serves as an exemplary study area for examining the mental health status of university students residing within closed campus environments.

## Data Collection

### Individual Demographic data

A questionnaire was conducted in May and June 2021 to collect individual data from students who live on the campus. We also submitted an ethical approval form and a risk assessment form, which were approved by UCL's ethics committee. The survey was formulated following the guidelines outlined by Regmi et al. (2017), to streamline the process of collecting responses. We developed a questionnaire containing questions designed to elicit demographic data such as age, education, and gender, as well as questions about travel ability and travel patterns such as whether the respondent possessed a driving licence or a public transport card, and users' main mode of travel. Following a manual screening process that eliminated 154 invalid participants, a comprehensive set of 811 valid responses was successfully collected from 10 universities within Guangzhou HEMC.

### Street-View Images

According to Lu et al. (2019), street-view images hold promise as indicators of pedestrians' perceptions of their surrounding environments. Due to the unavailability of Google in China, this study utilised Baidu Maps to obtain street-view images (referred to as BSV). Baidu Maps provides an extensive collection of street-view images encompassing over 300 Chinese cities (Zhou et al., 2019), making it a valuable and reliable alternative data source of high quality. The panoramic street-view API interface provided by Baidu Maps allowed us to collect images facing in all directions, which made the measurement of green space more accurate. The image processing was carried out as follows. Firstly, road vector elements were imported throughout the study area using ArcGIS software. Secondly, sampling points were generated along the street network to determine the locations for capturing images, with their corresponding coordinates recorded using ArcGIS software. The sam-

pling points were divided evenly across the vector elements of the streets, taking into account the size of the survey area (Fig. 2). We selected sampling points along the streets because the streetscape images were taken by vehicles. This also made it easier to measure green space exposure because, in most cases, people walked along the streets. After removing 27 images that did not provide an accurate reflection of aspects of the street, such as those that were obscured by large objects and those that were over- or under-exposed, 1,316 sample images were obtained from Baidu Maps.

### Remote Sensing Data

The NDVI has been widely employed in previous research (Almanza et al., 2012; Orban et al., 2017) to evaluate exposure to greenery exposure based on remotely sensed images. The NDVI is derived from the reflectance measurements in the near-infrared band and visible spectrum, obtained through satellite images (Wu et al., 2021). In this study, the NDVI values were computed using Landsat 8 with a resolution of 30 m. The resulting NDVI values ranged from −1 to 1, with higher values indicating increased exposure to greenery.

## Methods

### Deep Learning Technology

Semantic segmentation, a deep learning technique that is widely applied in urban studies, has been widely utilised to assess greenery from street-view images (Cheng et al., 2017; Helbich et al., 2021; Li et al., 2015; Wang et al., 2021b) using methods such as FCN-8s and U-Net (Badrinarayanan et al., 2017; Middle et al., 2019; Zhou et al., 2019). Yao et al. (2019) applied FCN-8s to carry out the semantic segmentation

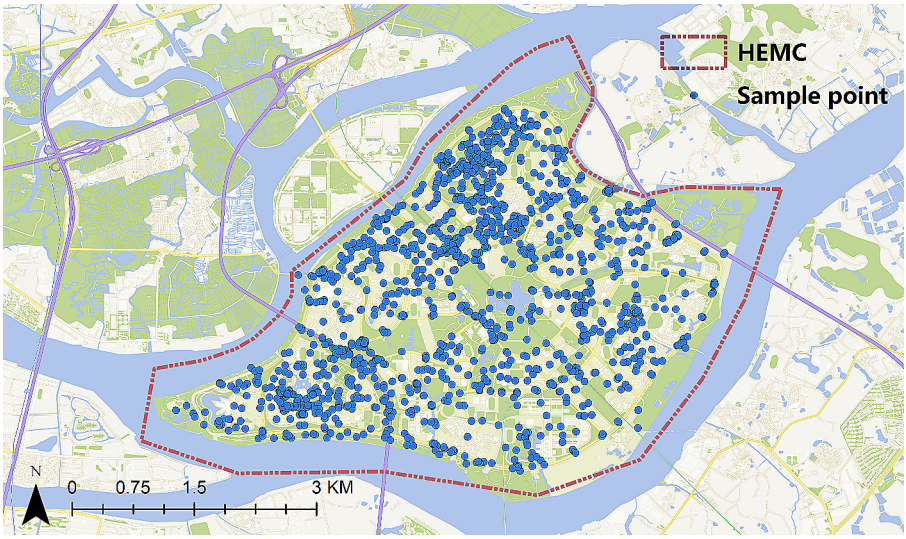


**Fig. 2** The plot of sample points used for extraction of street-view images

of street-view images and yielded satisfactory results in terms of assessing environmental perceptions. Therefore, following Yao et al.'s (2019) approach, we employed FCN-8s to estimate green space exposure from street-view images (further details are provided in the subsequent section). This allowed us to identify a comprehensive range of over 150 object categories (Long et al., 2015), including trees and vehicles. The FCN-8s method enables pixel-level prediction of the semantic properties of objects (Badrinarayanan et al., 2017). The green space index (GSI) for each sampling point was measured by computing the ratio of pixels within various green space categories to the total number of pixels in the respective street-view image. The GSI for each campus was computed using ArcGIS software (Li & Ghosh, 2018).

### Variables

Following previous studies (Liu et al., 2022a; Wang et al., 2019c), mental health issues (MHI) were selected as the dependent variable in our study. Respondents were required to answer 4 questions regarding the following aspects of their mental health: depression, nervousness, distraction and frustration, using a mental health rating scale. They were asked to rank them in order of severity from 0 to 4, meaning that the results ranged from possible totals of 0 to 16, which were recorded as continuous variables. Higher values indicated more severe mental health issues. The Cronbach's alpha value for the scale was 0.7.

Table 1 shows the definitions and descriptive analysis of all the variables included in this study. To account for potential confounding factors, demographic variables were controlled for, in line with prior studies (Liu et al., 2020; Wang et al., 2021a). Additionally, in order to explore the impact of travel factors on psychological well-being, travel-related variables such as ownership of a driving licence, possession of a public transport card, and the primary mode of travel, were also taken into account as control variables. Given the mandatory requirement for Chinse university students to reside in on-campus dormitories, the data were stratified based on the geographical location of the respective campuses where they resided, thus providing a structural framework for the analysis.

Table 1 presents an overview of the respondents' characteristics. The average mental health issues score (MHI) of the respondents was 7.88. The mean Green Space Index (GSI) across all ten university campuses was calculated as 17.04%, indicating that the level of greenery within Guangzhou HEMC is comparatively low. In terms of demographic attributes, the respondents had an average age of 22 years, with 83.1% holding a Bachelor's degree or below. Approximately half of the respondents (50%) had an income of less than 2,000 RMB per month, while only 10% earned more than 4,000 RMB per month. Females constituted slightly over half of the sample, and approximately one-third had a local household registration (37%). Additionally, 35.3% of the respondents reported having a partner. In terms of travel characteristics, 52%, 71%, and 47% of the respondents possessed a driving licence, a public transport card, and a monthly sharebike card, respectively. Almost a third of the respondents travelled mainly by bicycle (30%) and metro (29%), with the fewest number travelling by car (6%).

**Table 1** Descriptive analyses

| | Variables | Categories / Range (unit) | Percentage (and number) / Mean (and SD) |
|---|---|---|---|
| Dependent variables | MHI | (0–16) | 7.89 (3.69) |
| Independent variables | GSI | 12.90–23.35 (%) | 17.04% (2.55) |
| | NDVI | 14.52–17.96 (%) | 16.58% (1.02) |
| Demographic variables | Gender | Men | 39 (320) |
| | | Women | 61 (491) |
| | Age (years) | | 22 (5.20) |
| | Educational attainment level | Undergraduate and below | 83 (674) |
| | | Postgraduate and above | 17 (137) |
| | Driving licence | Yes | 52 (422) |
| | | No | 48 (389) |
| | Income | <2,000 RMB per month | 50 (404) |
| | | 2,000–4,000 RMB per month | 40 (321) |
| | | >4,000 RMB per month | 10 (86) |
| | Hukou status | Local hukou | 37 (298) |
| | | Non-local hukou | 63 (513) |
| | Partner relationship status | Partner relationship | 35 (286) |
| | | No partner relationship | 65 (525) |
| Transport abilities | Driving licence | Yes | 52 (422) |
| | | No | 48 (389) |
| | Public transport card ownership | Yes | 70 (577) |
| | | No | 30 (234) |
| | E-bike card ownership | Yes | 47 (383) |
| | | No | 53 (428) |
| Travel mode | Main travel mode | Car | 6 (47) |
| | | Bus | 16 (126) |
| | | Metro | 29 (239) |
| | | Bike/e-bike | 30 (244) |
| | | Walking | 19 (155) |

## Data Analyses

In this study, multilevel linear regression modelling was employed to investigate the relationship between green space exposure and mental health issues among university students (Raudenbush & Bryk, 2002), following methodologies established in previous studies (Liu et al., 2020; Wu et al., 2021). In the models, there was a hierarchical relationship whereby individuals categorised as level 1 were incorporated within the structure of university campuses, which were designated as level 2. The average variance inflation factor (VIF) of the variables in the models was found to be 1.96. In this study, a stepwise approach was adopted to examine the relationship between green space exposure and the mental health of university students. Firstly, Model 1 included only independent and socioeconomic variables. Given the potential link between travel behaviour and mental health established in prior research (Mackett, 2021a), the ability to travel variable was subsequently incorporated into Model 1, which then became Model 2. In the third iteration, individual travel patterns were

further controlled for in Model 2, which in turn became Model 3. This sequential modelling approach allowed an exploration of how individual travel characteristics moderated the relationship between campus green space exposure and the mental well-being of university students to be undertaken.

### Robustness Tests

We then conducted additional robustness tests on Model 3 to ensure the stability of the results (Models 4–6). Firstly, we quartiled the mental health issues variable and re-ran the regression (Model 4). Secondly, taking into account the potential effects of financial pressures on mental health issues among university students (Högberg, 2021), individuals with a monthly income exceeding 4,000 RMB were excluded from the sample, and the adjusted models were re-estimated (Model 5). Subsequently, given that levels of educational attainment have been shown to have an impact on mental health (Jiang et al., 2020), respondents with a Master's degree or higher were excluded from the sample, and the regression analysis was re-run (Model 6).

## Results

### Street-view Greenery Results

The visual results obtained using image segmentation and GSI are shown below. Figure 3 depicts a subset of the outcomes derived from the segmentation procedure employing FCN-8s. The model that was used effectively delineated various compo-

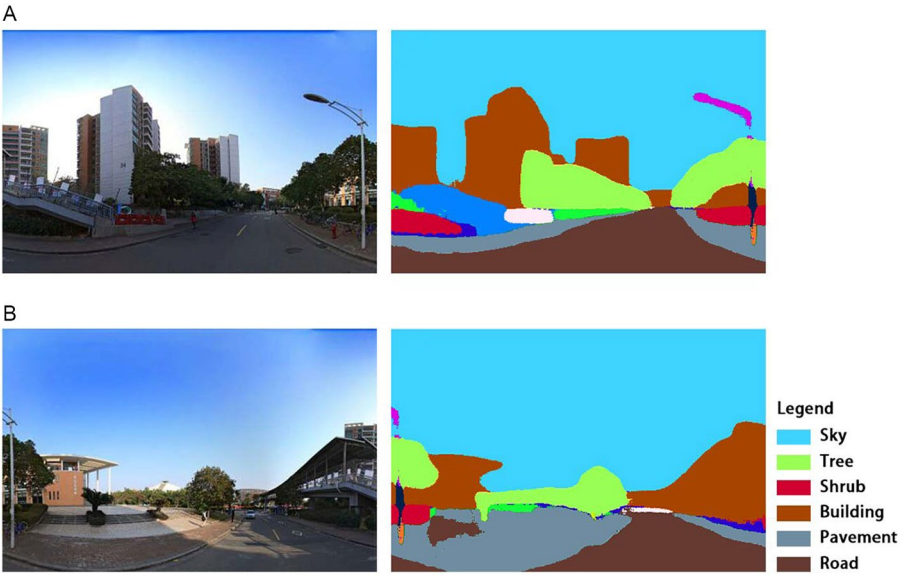


**Fig. 3** A sample of the image segmentation results obtained using FCN-8s. **(A)** Street-view images, and **(B)** Segmented images

nents of the urban built environment, including streets and buildings, as well as elements of vegetation such as lawns and trees, with a high level of precision.

Figure 4 shows a plot of the GSI derived from the analysis of street-view images and the NDVI generated from remote sensing images of Guangzhou HEMC. The continuous surface image of the GSI was generated by interpolation in ArcGIS software. A distinct difference in the spatial distribution of the two indicators can be observed.

## Baseline Results

Table 2 presents the results of the multilevel linear regression models. Model 1 examined the association between respondents' mental health issues and the underlying demographic variables. The results from all three models consistently showed a negative correlation between campus green space and respondents' mental health issues, while controlling for other variables. More specifically, undergraduates exhibited a higher likelihood of experiencing mental health issues compared to postgraduates (Coef. = -0.548, S.E.= 0.262). Additionally, respondents with a partner had a higher probability of experiencing mental health issues (Coef. = 0.875, S.E. = 0.209). Conversely, socio-demographic factors such as gender, age, and monthly income did not have statistically significant impacts on respondents' mental health.

Model 2 included respondents' transportation abilities, while the main travel mode variable was subsequently incorporated in Model 3. The findings from the three models consistently showed that individuals exposed to a greater quantity and quality of green space were less likely to experience psychological issues (GSI: Model 1: Coef. = -0.656, S.E. = 0.103; Model 2: Coef. = -0.655, S.E. = 0.101; Model 3: Coef. = -0.655, S.E. = 0.099; NDVI: Model 1: Coef. = -1.183, S.E. = 0.272; Model 2: Coef. = -1.167, S.E. = 0.269; Model 3: Coef. = -1.130, S.E. = 0.264). In order to explore how the travel behaviours of university students affect the association between campus greenery and their psychological well-being, travel characteristics were introduced in Models 2 and 3. The results showed that most of the travel behaviour variables did not significantly influence the relationship between campus greenery and mental health issues. However, a correlation between travel patterns and mental health issues among university students was found. More specifically, respondents who regularly

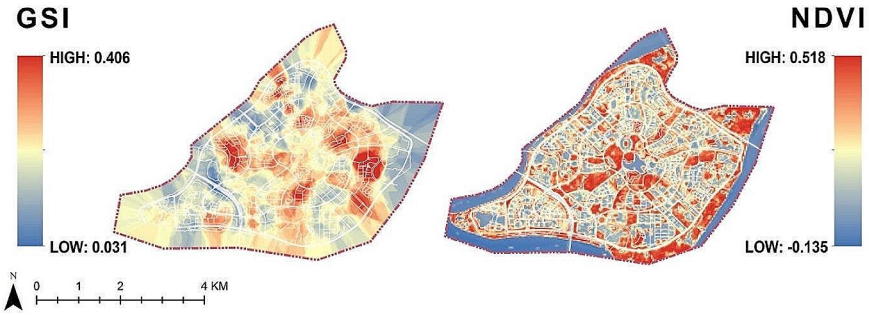


**Fig. 4** Comparison of GSI and NDVI for Guangzhou HEMC: **(A)** GSI **(B)** NDVI

**Table 2** Baseline results for predicting mental health issues

| | Model 1<br>Coef. (S.E.) | Model 2<br>Coef. (S.E.) | Model 3<br>Coef. (S.E.) |
|---|---|---|---|
| Fixed Part | | | |
| Independent variables | | | |
| GVI | -0.656***(0.103) | -0.655***(0.101) | -0.655***(0.099) |
| NDVI | -1.183***(0.272) | -1.167***(0.269) | -1.130***(0.264) |
| Covariates | | | |
| Demographic variables | | | |
| Women (ref: men) | 0.198(0.194) | 0.128(0.200) | 0.193(0.199) |
| Age | 0.029(0.020) | 0.034(0.020) | 0.036(0.020) |
| Educational Attainment (ref: undergraduate and below) | | | |
| Postgraduate and above | -0.548*(0.262) | -0.588*(0.265) | -0.555*(0.263) |
| Income level (ref: <2,000 RMB per month) | | | |
| 2,000–4,000 RMB per month | -0.034(0.208) | 0.004(0.212) | -0.007(0.210) |
| Above 4,000 RMB per month | 0.185(0.356) | 0.245(0.361) | 0.131(0.363) |
| Local hukou (ref: non-local hukou) | 0.016(0.200) | 0.056(0.201) | 0.017(0.200) |
| Partner relationship (ref: no partner relationship) | 0.875***(0.209) | 0.886***(0.209) | 0.835***(0.209) |
| Transport abilities | | | |
| Driving licence (ref: no driving licence) | | -0.121(0.201) | -0.133(0.200) |
| E-bike card ownership (ref: no e-bike card ownership) | | -0.259(0.195) | -0.300(0.198) |
| Public transport card ownership (ref: no public transport card ownership) | | -0.375(0.215) | -0.336(0.214) |
| Travel mode | | | |
| Bus (ref: travel by car) | | | -0.257(0.464) |
| Metro (ref: travel by car) | | | -0.796(0.433) |
| Bike/e-bike (ref: travel by car) | | | -0.532(0.438) |
| Walking (ref: travel by car) | | | -1.266**(0.458) |
| Constant | 37.782***(4.222) | 37.855***(4.170) | 37.845***(4.106) |
| Random Part | | | |
| Var (Universities) (Estimate) | -0.274(0.254) | -0.288(0.255) | -0.310(0.257) |
| Var (Residual) (Estimate) | 0.972***(0.025) | 0.968***(0.025) | 0.960***(0.025) |
| Number of individuals | 811 | 811 | 811 |
| Number of universities | 10 | 10 | 10 |
| AIC | 3921.534 | 3921.539 | 3915.216 |

*Note*: Coef. = coefficient; SE = standard error; AIC = Akaike information criterion. *$p<0.05$, **$p<0.01$, ***$p<0.001$

travelled on foot demonstrated better mental health than those who predominantly used cars as a method of transportation (Model 3: Coefficient = -1.266, Standard Error = 0.458). No significant disparities in mental health were observed for the other modes of travel.

### Robustness Check

Table 3 provides a summary of the robustness tests that were used to examine the relationship between campus greenery and mental health issues among university students at Guangzhou HEMC. Although slight variations in the coefficients were observed, the statistical significance of the association between campus greenery and mental health issues persisted, and the coefficients remained consistent across Models 4–6 in the robustness tests.

## Discussion

### Main Findings

To investigate the association between green space exposure and the mental health of university students, this study employed street-view images to evaluate green spaces and accurately determine individuals' perceived exposure to such environments. Controlling for individual socio-demographic variables, we observed a negative relationship between exposure to campus greenery and mental health issues among Chinese university students. Our findings corroborate various theories, such as attention recovery theory (Kaplan & Kaplan, 1989) and stress reduction theory (Ulrich et al., 1991), which have been proposed to elucidate the positive impact of exposure to greenery on mental well-being. Similar findings have been reported by other scholars (Triguero-Mas et al., 2015; Liu et al., 2019a, 2023), including those investigating the mental health of adolescents (Li & Sullivan, 2016; Zhang et al., 2022). For example, Liu et al. (2022b) examined the psychological well-being of university students residing on campus and found that campus green spaces positively contributed to their mental well-being.

In addition to the role played by green spaces in relation to mental health, our study identified a significant relationship between travel patterns and mental health issues among university students. This finding aligns with existing literature highlighting the positive effects of physical activity, such as walking, on mental well-being (Bai et al., 2021; Wang et al., 2023). Walking not only promotes physical health but also provides opportunities for relaxation, reflection, and connection with one's surroundings, which may help to reduce levels of mental health problems in individuals. Surprisingly, we also found that individual socio-demographic characteristics, specifically whether a person has a partner, have been shown to influence the level of mental health issues that they experience. However, the specific mechanisms underlying this relationship require further exploration. These additional factors add depth to our understanding of the relationship between exposure to green space and mental health among university students.

The utilisation of street-view images to investigate the impact of the natural environment on mental well-being has gained considerable traction in recent research (Helbich et al., 2019; Villeneuve et al., 2018). While this novel approach is becoming increasingly popular, our study revealed that both streetscape greenery and the NDVI exhibited negative associations with mental health issues. Similar findings have been

**Table 3** Robustness tests

| | Model 4<br>Coef. (S.E.)<br>Quadratic variables of mental health issues | Model 5<br>Coef. (S.E.)<br>Excluding respondents with a monthly income greater than 4,000 RMB | Model 6<br>Coef. (S.E.)<br>Excluding respondents with a Master's degree or above |
|---|---|---|---|
| Independent variables | | | |
| GSI | -0.209***(0.031) | -0.647***(0.102) | -0.655***(0.094) |
| NDVI | -0.318***(0.081) | -1.225***(0.272) | -1.104***(0.252) |
| Demographic variables | | | |
| Partner relationship (ref: no partner relationship) | 0.261***(0.064) | 0.825***(0.218) | 0.895***(0.239) |
| Travel mode | | | |
| Travel by foot (ref: travel by car) | -0.308*(0.139) | -1.890***(0.524) | -1.574**(0.526) |
| Number of individuals | 811 | 725 | 674 |
| Number of universities | 10 | 10 | 10 |
| AIC | 1984.913 | 3479.810 | 3288.039 |

*Note*: Coef. = coefficient; SE=standard error; AIC=Akaike information criterion. *$p<0.05$, **$p<0.01$, ***$p<0.001$

reported in other studies (Helbich et al., 2019; Larkin & Hystad, 2018). Additionally, Taylor et al. (2018) confirmed the association between the NDVI and psychological well-being in a study conducted in Australia; however, this same relationship was not observed in two cities in New Zealand that were also investigated. The underlying reasons for the disparities between the streetscape and remote sensing images may need further investigation, although the findings of our study imply that both approaches may effectively capture different facets of green space.

#### Mental Health Issues Among University Students

This paper yielded the following findings regarding the mental well-being of university students. First, from an ecological perspective, many scholars have found that green space may have different effects on various social groups (Gubbels et al., 2014; Kremers et al., 2006). However, in our study, we found that campus green space exposure significantly mitigates mental health issues among university students, challenging the findings of previous research suggesting that the effects vary across different demographic groups (Helbich et al., 2019, 2021). Our study demonstrated a consistent positive association between green space exposure and mental health across different population groups, thereby challenging previous research.

Second, previous studies have claimed that the effects of green space exposure on mental health may differ according to individual demographic characteristics (Högberg, 2021; Jiang et al., 2020). By comparing the results of our study with previous research on mental health in Guangzhou and China (Chen & Yuan, 2020; Liu et al., 2019b; Wang et al., 2021c; Xiao et al., 2020), we observed a notable difference in the mental health levels of university students and both the general population and older adults. Specifically, the mental health level of university students in Guangzhou appeared to be significantly lower than those of both comparison groups. Furthermore, the difference in mental health levels between the university student group and these comparison groups was notably larger, indicating a distinct disparity in mental well-being among university students. However, our study did not find any connection between mental health and gender among university students, contrary to previous findings for other social groups (Buttazzoni et al., 2022; Feng et al., 2022). It is unclear why our findings challenge previous evidence about gender differences, but it could potentially be attributed to the restricted living environment of the Chinese university students who participated in the research (Sun et al., 2018). These findings underscore the unique mental health challenges faced by university students in Guangzhou compared to other demographic groups within the region.

Third, our findings suggest an association between travel characteristics and mental well-being, with regular walkers experiencing better mental health than those who primarily relied on driving. This relationship may be attributed to the well-established link between mental well-being and physical activity (Cao & Hickman, 2019; Gubbels et al., 2016; Manley et al., 2021; Triguero-Mas et al., 2015). Furthermore, green space may facilitate physical activity, which in turn benefits mental health (Hunter et al., 2015; Mytton et al., 2012; Sallis et al., 2016). Therefore, further research is warranted to investigate physical activity as a potential mediator in the relationship between mental well-being and exposure to greenery.

## Policy Implications

Our study suggests several policy implications for public health and urban development. Firstly, the results demonstrate the positive influence of green space on mitigating mental health issues, emphasising the importance of integrating green space into urban development. To foster a healthy community, policymakers and urban planners should prioritise the effects of urban green space, especially in urban areas (Ziari et al., 2018; Kim & Park, 2014). Existing research has indicated that an accessible green environment positively influences well-being and travel behaviour (Lotfata et al., 2023; Ta et al., 2021; Zhou et al., 2022), which aligns with our findings regarding the relationship between exposure to greenery and mental well-being (Buttazzoni et al., 2022). Consequently, it is not solely a matter of increasing the quantity of green space but also improving its accessibility. In future urban planning, emphasis should be placed on the development of accessible green spaces, including rooftop gardens and pedestrian greenways (Han, 2007). Additionally, for individuals residing in constrained environments, indoor greenery is vital for enhancing their well-being. Secondly, this study underscores the association between factors associated with the natural environment and the mental well-being of young individuals. The continued impact of adolescent mental health development on individuals in adulthood has been established by Culpin et al. (2022), and this phenomenon may have implications for the long-term growth, prosperity and sustainability of society. As built environment factors can be predictors of mental health, policymakers and urban designers need to pay more attention to environmental changes that may affect the well-being of young people. Finally, this study found a link between individuals' mental health and travel patterns, which confirms Mackett's (2021a) assertion that mental health issues can limit people's travel mode choices. Mackett's study of people with mental health issues found that making improvements to the transport infrastructure and services facilitated travel for this group (Mackett, 2021b). Therefore, policymakers should take the needs of vulnerable people into account and improve urban transport services to try to achieve the goal of greater social inclusion.

## Limitations

The study also has a few limitations. Firstly, the characteristics of the research site are unique to China. Most Chinese university campuses are closed, gated communities, which is not the case for Western universities. Therefore, the findings of this study might not be applicable to some Western countries. Secondly, respondents' exposure to green spaces was calculated using street-view images of university campuses, so the calculations may not be as accurate as those obtained using the Global Positioning System. This could compromise our ability to identify a stable and reliable link between green space and university students' mental well-being. Thirdly, the data collection was carried out in 2021, during a period marked by various COVID-19 restrictions, which may have influenced levels of well-being among students. Therefore, it is essential to consider the potential impact of COVID-19 on our findings. Fourthly, while our study relied on street-view images by using deep learning techniques to assess green space availability, it is important to acknowledge that other

methodologies, such as street network analysis (Chen & Chang, 2015; Xiao et al., 2017), mobile phone data (Guo et al., 2019; Lin et al., 2021; Xiao et al., 2019), and GIS techniques (Fan et al., 2017), have also been explored in recent research, especially in China. These alternative approaches offer unique insights into green space access and utilisation patterns, which may provide additional perspectives on the relationship between green spaces and mental health. Incorporating these innovative approaches in future research could lead to a more comprehensive understanding of the complexities surrounding access to green space.

## Conclusions

University campuses in China are characterised by a spatial organisation pattern that differs from those in other countries worldwide, meaning that students who study there may experience additional mental health issues. This study explored the relationship between exposure to visible forms of campus green space and mental health issues among university students on closed university campuses. We examined this relationship using streetscape images, remotely sensed images, deep learning techniques and multilevel linear regression models, as well as investigating the link between the individual characteristics of university students and their mental well-being. The results showed that exposure to campus greenery significantly mitigates the level of mental health issues among university students. Our analysis revealed that individual socio-demographic characteristics such as educational attainment and whether one has a partner influence individuals' mental health status, while individual travel patterns were also associated with mental health issues. From a methodological perspective, our study showed that using remote sensing or streetscape images to measure green space does not affect the stable association between green space and mental well-being. To create a healthier community and achieve greater social inclusion, urban planners need to focus on increasing green space exposure and improving urban transport services.

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### Declarations

**Conflict of interest** The authors declare that they have no conflict of interest.

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## Authors and Affiliations

**Yihang Bai[1,6] · Ruoyu Wang[2] · Linchuan Yang[3] · Yantao Ling[4] · Mengqiu Cao[5]**

✉ Mengqiu Cao
m.cao@westminster.ac.uk

Yihang Bai
gyyb@leeds.ac.uk

Ruoyu Wang
rw24347@essex.ac.uk

Linchuan Yang
yanglc0125@swjtu.edu.cn

Yantao Ling
lingyantao@cqut.edu.cn

1 School of Geography, University of Leeds, Leeds, UK

2 Institute of Public Health and Wellbeing, University of Essex, Essex, UK

3 Department of Urban and Rural Planning, School of Architecture, Southwest Jiaotong University, Chengdu, China

4 School of Economics and Finance, Chongqing University of Technology, Chongqing, China

5 School of Architecture and Cities, University of Westminster, London, UK

6 Leeds Institute for Data Analytics, University of Leeds, Leeds, UK