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Green at eye level: Exploring the impacts of visible greenery on physical activity among university students

Yihang Bai [a,b], Mengqiu Cao [c,*], Yiwei Bai [d], Kaihan Zhang [e], Xinyao Song [c], Ruoyu Wang [f]

[a] School of Geography, University of Leeds, Leeds, United Kingdom
[b] Leeds Institute for Data Analytics, University of Leeds, Leeds, United Kingdom
[c] Bartlett School of Environment, Energy and Resources, University College London, London, United Kingdom
[d] School of Architecture, South China University of Technology, Guangzhou, China
[e] Cho Chun Shik Graduate School of Mobility, Korea Advanced Institute of Science and Technology, South Korea
[f] Institute of Public Health and Wellbeing, University of Essex, Essex, United Kingdom

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ABSTRACT

Urban green spaces are vital for promoting physical activity and have a recognised positive impact on public health. Research consistently shows high levels of physical inactivity among adolescents, with their exercise habits influencing future travel behaviours. While most studies focus on neighbourhood settings, this study explores university campuses in China. Unlike Western campuses, Chinese universities are typically enclosed by physical walls, presenting unique spatial dynamics. This research involved a survey of 811 students across ten universities in Guangzhou, employing the International Physical Activity Questionnaire (IPAQ) to assess their levels of physical activity. To evaluate greenery from a pedestrian's perspective, we applied a deep learning semantic analysis of street-view images. This method is consistent with human visual experience, providing a novel way to analyse campus green spaces. A multilevel linear regression model was used to explore the link between green space exposure and student physical activity within these enclosed environments. The findings indicate a significant positive correlation between accessible green spaces at eye-level and students' physical activity. In addition, active travel behaviours, such as walking, correlate positively with greater physical activity among students. However, our study found no significant connection between green spaces analysed via remote sensing and student activity levels. These insights underscore the importance of integrating green spaces into urban planning to foster healthier communities.

1. Introduction

In recent years, insufficient physical activity (PA) has become a widespread global concern, which poses a severe threat to public health [16]. Approximately one-third of the global population falls short of achieving sufficient levels of PA [30]. This issue is particularly pronounced in China, where weekly PA levels among adults decreased by 31 % between 1991 and 2011 [59]. Numerous studies have linked physical inactivity to declines in physical function and increased rates of preventable deaths [6,31,79]. Environmental improvement has been proven to offer a useful means of promoting PA and therefore addressing this issue [62]. Urban green spaces, such as parks and green corridors, can provide attractive settings for participating in PA [56,86]. Extensive research has established the role of green spaces in promoting PA [66,71,81,91], with studies highlighting increased engagement in walking and cycling due to green environments [4,15,19]. A study by Li et al. [50] demonstrates how large-scale greenway interventions, like those implemented in Wuhan, China, significantly decrease sedentary behaviour, suggesting that the design of urban environments can play a crucial role in promoting more active lifestyles. However, despite extensive studies into their correlation, findings about the impact of green space on PA still remain inconsistent [42]. Most prior research has affirmed that green space has a beneficial impact on the frequency of PA [54,74]. For instance, Almanza et al. [3] found that children who had >20 min of green space exposure per day engaged in significantly more physical activity than those who had no exposure to green space. However, some scholars have reported a negative association between green space exposure and physical activity [36,60]. For example, a study

* Corresponding author.
E-mail address: mengqiu.cao@ucl.ac.uk (M. Cao).

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conducted by Hillsdon et al. [36] in Norwich, in the UK, reported no definitive association between exposure to greenery and recreational activity. Meanwhile, Kaczynski et al. [40] identified that neither the size of, nor distance to green space significantly affect levels of PA. Additionally, much of the research has focused on residential or workplace environments as study sites [10,82,85], but fewer studies have investigated unique settings such as university campuses, particularly enclosed environments such as those in China, where green spaces may play distinct roles.

We found at least four types of potential research gaps in our study of the existing literature. Firstly, PA is not solely confined to neighbourhood settings, but could also take place in distinct locales, such as workplaces [82] and educational institutions [87]. Bai et al. [4] examined the impact of green spaces on active travel behaviours within university campuses, and Yang et al. [87] used Hong Kong as a case study with which to investigate the link between green space around schools and pupils' PA. Nevertheless, substantial disparities exist between university campuses in China and their counterparts in Western nations. In China, many university campuses operate as self-contained environments which are often referred to as 'enclosed campuses'. It is not uncommon for university campuses in China to be planned and constructed as separate living spaces isolated by boundary walls due to management and historical reasons [70]. These are physically enclosed by boundary walls or fences, with entry and exit points regulated by security personnel. Within these campuses, students have access to essential facilities such as dormitories, teaching buildings, libraries, sports complexes, dining halls, and commercial amenities. Dormitories are provided on gated campuses at a cost well below market rates due to government subsidies, thus ensuring that students can enjoy good living conditions [70]. Daily activities, including commuting, studying, exercising, and socialising, are largely confined to the campus premises. While students can leave campus, movement is typically subject to institutional rules or permission protocols, particularly during events like public health emergencies. Consequently, this level of spatial enclosure directly influences patterns of accessibility, mobility, and physical activity among students. For example, the frequency of off-campus travel among Chinese university students was half that of Thai and American university students on average [12,51,90]. Therefore, studying the environmental factors that influence PA in a particular setting can contribute to the health of the university population. However, while most studies have focused on students in open university settings [5,68,76], research into PA behaviour on enclosed campuses remains scarce [90].

Secondly, there is a notable gap in research concerning the built environment factors associated with physical activity (PA) among adolescents. According to the World Health Organisation [80], the majority of young people are not achieving the recommended minimum levels of PA. Furthermore, the Centers for Disease Control and Prevention (CDC) [11] claims that over half of university students in the United States are physically inactive, with approximately one-third of them never engaging in exercise. Furthermore, it is widely acknowledged that the PA habits developed during this period of life will also determine a person's level of PA after they graduate from university [38]. Similarly, it is essential to gain a better understanding of the travel behaviour of university students in order to predict future travel patterns and develop transport facilities [93]. The travel habits formed during an individual's school and university years are likely to influence their future travel patterns [58,73]. For example, the behavioural habits that students form during their time at university may have a significant effect on determining their attitudes towards travel after graduation, thus influencing their future travel behaviour [67], and providing the motivation for this study to concentrate on exploring the link between PA among university students and built environment factors.

A third factor contributing to inconsistencies is the variability in the relationship between green space and PA, which is influenced by the measurement methods employed. Traditionally, remote sensing has commonly been used to measure green spaces in studies [34,52]. However, these top-down views from remotely sensed images may not accurately represent how green spaces are perceived at eye level [4,18,55,75]. For example, in some commercial streets tree canopy may be dense but not visible from street level, as it may be obscured by buildings. Consequently, eye-level measurements obtained using street-view images provide a more precise evaluation of green spaces that can be used for studying their impact on PA. Although both street-view and satellite images can be used to quantify greenness, they differ significantly in terms of perspective and environmental representation. Metrics derived from satellite imagery provide a top-down view of canopy coverage (typically measured using Normalised Difference Vegetation Index, NDVI), while those derived from street-view images capture greenness that is visible at eye level, thus aligning more closely with human perceptions. Despite this, methodological constraints have limited the number of studies comparing the effects of green space on PA using different measurement approaches [4,81]. For instance, Yang et al. [86] found that more street greenery could promote walking behaviour in older people by analysing street-view images. Similarly, Lu [54] assessed green space using Google street-view images, and confirmed that street greenery at eye level positively impacted recreational PA. Therefore, there is a critical need to explore how the association between green space and PA among university students varies when assessed with different measurement techniques.

The fourth reason for the differences in study findings is connected with the structure of the data regarding PA. Most previous research investigating PA and green space has used quantitative methods. However, stable conclusions cannot be drawn from cross-sectional studies alone, as there may be a relationship of inverse causality between the two variables, for example the issue of self-selection could come into play [85]. For example, suppose that people actively choose to live in environments with higher levels of green space. The results, in this case, may find no significant link between green space and PA. Therefore, higher levels of PA might be more influenced by individual characteristics than by environmental factors such as people's surroundings [28]. People with a propensity to be active will probably choose to live in communities with more green space, which also leads to higher levels of PA [10,26]. To overcome this limitation, this study used multilevel linear regression modelling with a hierarchically nested structure. Moreover, our study was also able to mitigate residential self-selection bias as the Chinese university students were randomly assigned to the campuses on which they live.

In line with this perspective, our study seeks to address these gaps by exploring the relationship between green space and PA levels among university students using different green space measurements. We employed the International Physical Activity Questionnaire (IPAQ) to measure students' PA, and two green space metrics - NDVI (from satellite imagery) and Green View Index (GVI, from street-view imagery) - were calculated to assess their respective impacts on PA, which are increasingly popular in recent studies investigating PA [42,54,83]. In this study, we chose university students as the subject of investigation, as their PA patterns have become predominantly individually driven. We identified the Higher Education Mega Centre in Guangzhou, China (HEMC), as the site of investigation due to the substantial amount of greenery it contains, the high density of the student population, and the fact that the campuses are enclosed. The Chinese government's promotion of active travel and physical activity, as outlined in the Healthy China 2030 initiative [69], highlights the critical role of the built environment in shaping public health outcomes. These policy priorities resonate with the planning principles of the HEMC, which features extensive green infrastructure and has a compact urban form, despite having been planned before the launch of the initiative.

Overall, having identified four key research gaps in relation to context, measurement, behaviour, and methodology, this study seeks to address two key questions: (RQ1) Does green space influence physical activity among university students, and if so; (RQ2) which metric of green space (eye-level or satellite-derived) more effectively explains variations in physical activity among Chinese university students on enclosed campuses? By investigating these issues, the research provides new insights into the relationship between green space and PA and offers evidence-based strategies for enhancing adolescent health outcomes through targeted campus design and urban planning.

2. Case study, data and methodology

2.1. Study area and population

Our research was conducted at the Guangzhou Higher Education Mega Centre (HEMC), a densely populated university cluster in the Panyu district of Guangzhou. Situated on Xiaoguwei Island in the Pearl River Delta, the HEMC is surrounded by the Pearl River, forming a semi-enclosed environment conducive to independent urban planning. The HEMC is a representative example of enclosed campuses in China, home to ten higher education institutions where over 180,000 students and 20,000 faculty members reside [37]. The HEMC covers approximately 17.9 km^2, with a population density exceeding 11,000 people/km^2 [64], reflecting the intensive land use model characteristic of China's higher education planning.

The HEMC is administered under a coordinated municipal planning framework, which aspires to create an 'internationally leading university district' [27]. While official demographic or travel-mode data are not publicly available, our survey shows that about 70 % of people have a bus or metro pass and nearly 70 % favour active travel (walking or cycling). The internal road network supports walking and cycling, with access to off-campus destinations controlled via campus gates. These figures demonstrate the prevalence of both public transport and non-motorized commuting among university students, illustrating the significance of green spaces and connectivity within the enclosed campus environment. Its distinctive geospatial layout, featuring an enclosed campus environment and high population density, makes it an ideal setting for studying the PA patterns of university students (Fig. 1)

Data from this study were gathered through a questionnaire survey was conducted between May and June 2021 among Chinese students aged 18 and over who were able to engage in PA independently. The survey incorporated trap questions and underwent manual screening to eliminate invalid responses, yielding a valid sample of 811 participants drawn from 10 universities within the HEMC.

2.2. Data

2.2.1. Physical activity among university students

The level of PA was assessed using the modified International Physical Activity Questionnaire (IPAQ), a widely accepted and reliable instrument for evaluating PA. The general validity and reliability of IPAQ have been widely confirmed [14]. The questionnaire was designed to elicit information about the PA levels within three domains: vigorous, moderate, and light-intensity activities. Vigorous activities, such as running or football, involve significant increases in respiration and heart rate, while moderate activities, like brisk walking or badminton, result in moderate physiological changes. Light activities, such as slow walking or table tennis, lead to minimal exertion. PA was assessed by the following questions: 1) How many days in the last 7 have you done vigorous physical activity? (e.g. playing basketball or fast cycling); 2) On average, how much time did you usually dedicate to vigorous physical activity on each day during a 7-day period/week? 3) How many days in the last 7 did you do moderate physical activity? (e.g. cycling or playing badminton) 4) On average, how much time did you usually dedicate to moderate physical activity on each day during a 7-day period/week? 5) How many days in the last 7 did you do light physical activity? (e.g., walking, playing table tennis) 6) On average, how much time did you usually dedicate to light physical activity on each day during a 7-day period/week? To accurately measure PA, we employed the Metabolic Equivalent Task (MET) as defined by Ainsworth et al. [1], which quantifies energy expenditure by indicating the exertion rate of an activity relative to the resting metabolic rate. PA data were converted to energy expenditure, expressed in MET - minutes, with higher values indicating more intense PA. The PA profiles were then normalised to a z-score for statistical analysis.

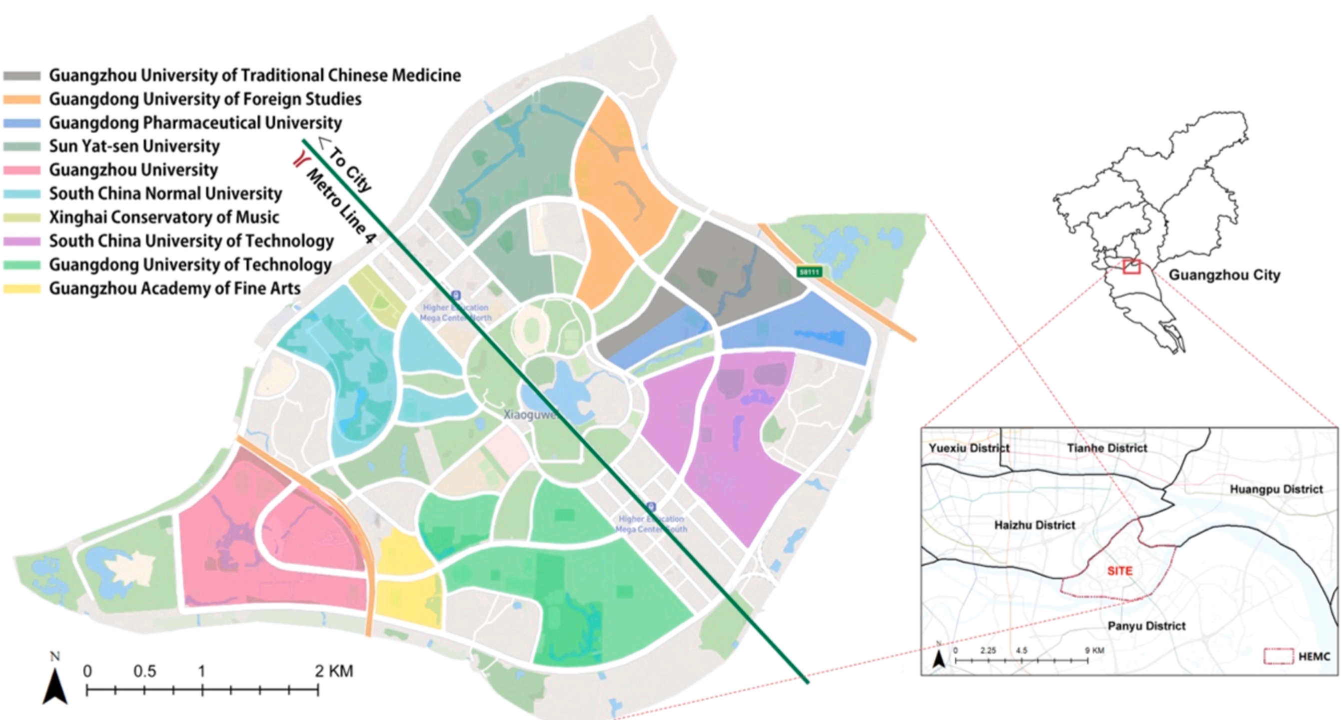

Fig. 1. Spatial Layout of the Guangzhou HEMC.

2.3. Campus green space

2.3.1. Eye-level greenery

He et al. [32] argue that the correlation between street-level greenery and PA is more important than other measures of green space. They suggest that street-view imagery serves as an effective means of assessing how pedestrians perceive their environment. We used Baidu Street View (BSV) and ArcGIS software (ESRI, USA) to measure street greenery. Baidu Maps is a mapping service widely used in China that provides high-quality street-view images, and can be considered a reliable source of this type of data [92]. Following the method used by Helbich et al. [35], we process the image as follows: First, we established a Baidu Maps API for extracting street view images. Next, we generated 1443 sampling points across the street network of Guangzhou HEMC, placing representative points along each street segment to ensure balanced spatial representation (Fig. 2). Finally, panoramic images were collected at each sampling point using the Baidu API to cover 360-degree street views. After excluding 127 images due to obstructions or mismatches with the location criteria, we retained 1316 sample images with which to conduct our evaluation of green space.

We then applied deep learning semantic segmentation algorithms to evaluate green space [81]. Deep learning techniques serve as a potent tool for object identification within images [46]. Semantic segmentation enhances the accuracy of colour classification in images by considering the contextual information in an image, rather than solely relying on the pixel, which helps differentiate between natural and artificial green objects [35,45,53]. In this study, we used fully convolutional neural networks (FCN-8s), which have demonstrated promising results in prior research [4,65,75]. These networks were trained to identify and quantify the distribution and proportion of green space within street-view images. The performance of the network was evaluated using pixel contrast accuracy, achieving 0.814426 with the training dataset and 0.66839 with the test dataset [88]. After the image segmentation, the GVI was calculated at each point by determining the proportion of green space pixels relative to the total number of pixels in the image. It is important to note that while the GVI was derived from sampling points across the HEMC, the survey data was collected at the individual level. To address this difference in scale, GVI values were aggregated at the university campus level using ArcGIS [47] to compare the degree of greenness between the various universities. It was assumed that students living within the same campus were exposed to a comparable level of visible greenery during their daily activities. This limitation was also mitigated through campus-level clustering in the multilevel model design. Fig. 3 illustrates the distribution of the GVI values across the HEMC.

2.3.2. Normalised difference vegetation index (NDVI)

The NDVI, a standard metric for assessing vegetation coverage, is derived from the reflectance values in the near-infrared (NIR) and visible spectra of satellite imagery [82]. In this analysis, the NDVI values were calculated from Landsat 8 satellite imagery with a spatial resolution of 30 m $\times$ 30 m. These values, ranging from -1 to 1, indicate the level of vegetation, with higher values reflecting greater vegetative density. ArcGIS was utilised to compute the NDVI for each university campus, the results of which are detailed in the descriptive analysis tables. Fig. 4 illustrates the spatial distribution of the NDVI values for Guangzhou HEMC.

2.4. Control variables

In this study, we controlled for various socio-demographic factors including gender, age, education, income, partner status and hukou status (a household registration system unique to China), following previous studies [9,49,52,89]. Gender was treated as a binary variable, assigning a value of 0 to respondents identifying as 'male' and 1 to those identifying as 'female'. Age was recorded as the respondent's current age at the time that the questionnaire was completed. Educational status was also quantified through a binary variable, with 1 signifying 'postgraduate and above' and 0 indicating 'undergraduate and below.' Personal income, in RMB per month, was categorised into three levels: <2000 (reference category), 2000–4000, and >4000. Partner status and hukou status were represented by dummy variables, where '1' signifies 'with a partner' and 'local household' respectively, and '0' represents 'without a partner' and 'non-local household'. In addition to socio-economic characteristics, individual travel characteristics were also considered in our study, including travel ability, the main mode of

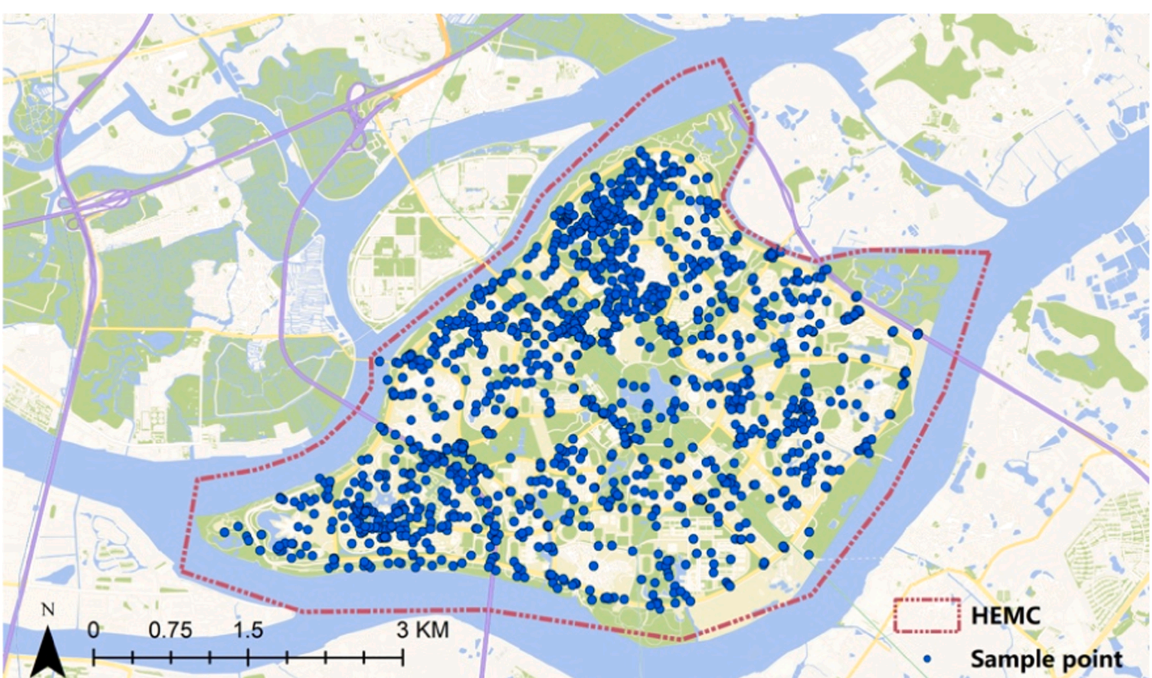

Fig. 2. Spatial Distribution of Sampling Points.

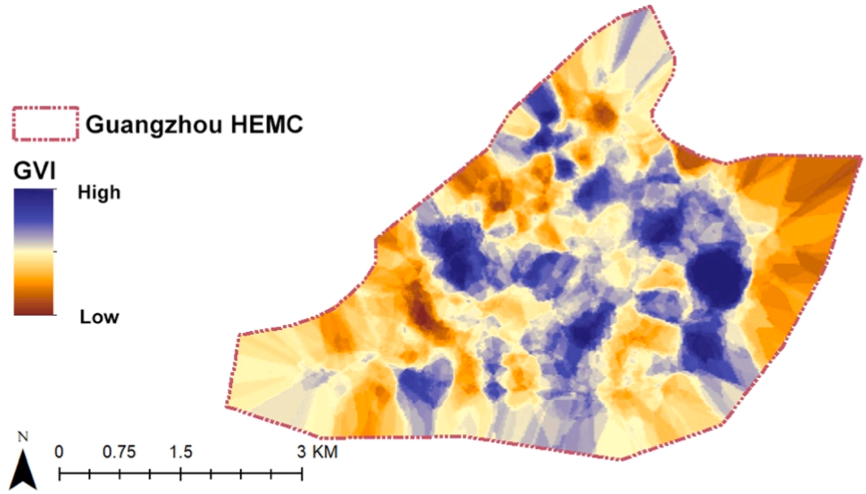

Fig. 3. Distribution of GVI values for Guangzhou HEMC.

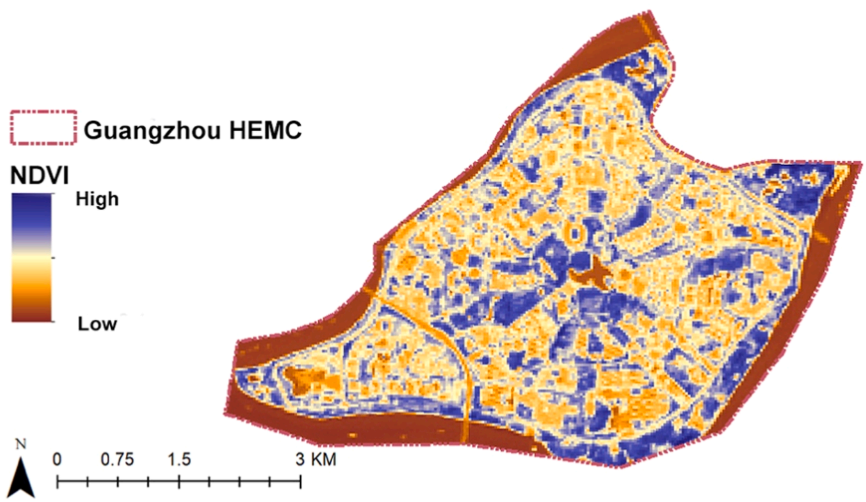

Fig. 4. Distribution of NDVI values for Guangzhou HEMC.

travel and active travel. The ability to travel includes the possession of a driving licence, a monthly bicycle sharing card and a public transport pass, measured by a binary variable where 1 means 'yes' and 0 means 'no'. We asked the question, "How did you travel mostly in the last 14 days", to determine the mode of transport, which included driving, metro, bus, bicycle/electric bike and walking. Finally, we assessed respondents' inclination toward PA to investigate the correlation between PA and active travel, which was represented by a binary variable. Furthermore, to ensure our data was structurally stratified, respondents were also asked, "Which university campus do you live on?"

2.5. Data analysis

The relationship between exposure to campus green space and PA was examined using multilevel linear regression models. Single-level regression models, which treat each respondent's PA outcomes as independent observations and do not account for hierarchical structures in the data, can lead to an overestimation of statistical significance [7]. Therefore, we used multilevel models, which took into account the nesting of respondents within neighbourhoods with similar levels of exposure to greenery and included socio-demographic variables as covariates [24]. PA scores were treated as continuous outcomes in the fully adjusted models [7]. Random intercepts were included to account for correlations due to the nesting of respondents within university campuses.

This study employed a stepwise approach to assess the impact of the natural environment on university students' PA levels. Initially, we regressed the association between respondents' PA status and street greenery (Model 1). Secondly, we further controlled for transport and travel ability covariates such as possessing a driving licence, bike-sharing or bus pass, based on Model 1 (Model 2). Third, due to the association between travel patterns and PA that has been evidenced in previous literature [41,77], Model 3 controlled for the main individual travel mode covariates, based on Model 2. Subsequently, in order to further investigate the influence of eye-level greenery within campus settings on various levels of PA in greater depth, we conducted additional regression analyses on Model 3 with light PA, moderate PA, and vigorous PA as separate dependent variables (Model 3a-3c). To examine the differences caused by how green space was assessed, we re-ran the model but replaced NDVI with eye-level greenery (Models 1a-3a).

To ensure the robustness of the findings, the best-fitting model (Model 3) stability was tested (Models 4a-4c). First, we re-ran the model with quartiled IPAQ scores (Model 4a). Next, given the influence of income on PA [17], Model 4b excluded respondents earning more than RMB 4000 per month. As educational background may also affect individual PA levels [29], respondents with a master's degree or higher were then excluded (Model 4c). The model performance was assessed using the Akaike Information Criterion (AIC), with lower values indicating the model has a better fit [8].

3. Results

3.1. Descriptive analysis

Table 1 shows the individual socio-demographic variables and indicators of green space exposure. On average, university students at Guangzhou HEMC had a relatively high level of PA (Mean = 1833.22, SD = 806.42) which was higher than the average physical activity energy expenditure of the adult population [39] and older individuals [84]. In terms of intensity levels, the highest energy expenditure was recorded for light PA (Mean = 667.45, SD = 309.99), followed by vigorous PA (Mean = 655.49, SD = 382.60) and moderate PA (Mean = 510.28, SD = 267.75). Active travel, such as walking or cycling, is popular among students. Our results show that about two-thirds of university students tend to travel actively (69 %), indicating these modes as their predominant forms of transport. Regarding built environment factors, all the green space indicators ranged from 0 to 1 in this study. The average GVI for the sites that were studied was 17 %. The median (16.78) was slightly less than the average of 17.04, suggesting a concentration of campuses with lower greenery levels. The NDVI also averaged 17 %, closely mirroring the GVI results, with a small standard deviation for both GVI and NDVI (2.55 and 1.02 respectively), providing a consistent baseline for PA analysis. Regarding the individual-level variables, the study involved a slightly greater number of female participants than males, with an average age of 22 years. Most respondents (83 %) held a bachelor's degree or lower, and about 37 % possessed a local hukou. The majority (90 %) reported a monthly income below RMB 4000. In terms of transport characteristics, more than half of the participants possessed a driving licence (52 %) and/or a monthly shared bicycle card (47 %), while only a third (30 %) did not possess a public transport card. Meanwhile, a third of respondents travelled mainly by metro or bicycle/e-bike (29 % and 30 % respectively).

Table 1
Descriptive statistics.

Category	Subcategory	Proportion (numbers)/mean (*SD*)	Median
Dependent variables			
Total physical activity (PA)	MET * MIN	1833.22 (806.42)	1980
Light PA	MET * MIN	667.45 (309.99)	660
Moderate PA	MET * MIN	510.28 (267.75)	480
Vigorous PA	MET * MIN	655.49 (382.60)	640
Independent variables			
Green View Index (GVI)	%	17.04 (2.55)	16.78
NDVI		0.17 (0.01)	0.17
Demographics			
Gender	Male	39 (320)	1
	Female	61 (491)	
Age	Years	22 (5.20)	0
Qualification	Undergraduate and below	83 (674)	0
	Postgraduate and above	17 (137)	
Income (RMB per month)	<2000	50 (404)	0
	2000–4000	40 (321)	
	>4000	10 (86)	
Hukou status	Local	37 (298)	0
	Non-local	63 (513)	
Partner relationship status	Yes	35 (286)	0
	No	65 (525)	
Transport abilities			
Driving licence	Yes	52 (422)	1
	No	48 (389)	
E-bike card ownership	Yes	47 (383)	0
	No	53 (428)	
Public transport card ownership	Yes	70 (577)	1
	No	30 (234)	
Travel mode			
Main travel mode	Car	6 (47)	2
	Bus	16 (126)	
	Metro	29 (239)	
	Bike/e-bike	30 (244)	
	Walk	19 (155)	
Active travel	Yes	69 (558)	1
	No	31 (253)	

3.2. Multi-level regression model

Table 2 displays the results regarding the correlation between campus eye-level greenery, socio-demographic factors, and personal travel characteristics in relation to PA. The analysis of PA levels among university students (Model 1) yielded a statistically significant positive association between eye-level greenery and PA ($p < 0.01$). A 1 % rise in

Table 2
Multilevel regression results: Impact of GVI on PA.

	Model 1 Coef. (S.E.)	Model 2 Coef. (S.E.)	Model 3 Coef. (S.E.)
Fixed Part			
Independent variables			
GVI	0.288** (0.068)	0.288** (0.068)	0.278** (0.065)
Covariates			
Demographic variables			
Female (ref: male)	0.034 (0.034)	0.034 (0.035)	0.031 (0.034)
Age	0.001 (0.004)	0.000 (0.004)	−0.001 (0.003)
Educational Attainment (ref: undergraduate and below)			
Postgraduate and above	0.077 (0.047)	0.085 (0.047)	0.088 (0.045)
Income (ref: Below 2000)			
2000–4000	−0.061 (0.037)	−0.056 (0.037)	−0.040 (0.036)
Above 4000	−0.046 (0.063)	−0.034 (0.064)	0.000 (0.062)
Local hukou (ref: non-local)	0.005 (0.035)	−0.009 (0.035)	−0.006 (0.034)
Partner relationship	0.017 (0.037)	0.014 (0.037)	0.030 (0.036)
Transport abilities			
Driving licence		0.035 (0.035)	0.047 (0.034)
E-bike card		−0.038 (0.035)	−0.053 (0.034)
Public transport card		0.101** (0.038)	0.085* (0.037)
Travel Mode			
Bus (ref: car)			0.031 (0.080)
Metro (ref: car)			0.001 (0.074)
Bike/e-bike (ref: car)			0.090 (0.076)
Walking (ref: car)			0.267** (0.080)
Active travel			0.162** (0.039)
Constant	−5.103** (1.176)	−5.152** (1.178)	−5.156** (1.126)
Random Part			
Var (Universities) (Estimate)	0.347* (0.157)	0.348* (0.157)	0.317* (0.143)
Var (Residual) (Estimate)	0.218** (0.011)	0.216** (0.011)	0.200** (0.010)
Number of individuals	811	811	811
Number of schools	10	10	10
AIC	1137.207	1134.016	1080.199

Note: * $p < 0.05$, ** $p < 0.01$.

eye-level greenery was associated with a 0.288 standard deviation increase in university students' PA, when other socio-demographic variables were controlled for (Coef. = 0.288, S.E. = 0.068). This finding suggests that exposure to greenery tends to enhance PA levels in young people. Additionally, no significant associations were found between PA and other individual socio-demographic variables such as age, gender, monthly income, household, and partner status.

Upon incorporating personal travel characteristics (travel ability and mode) into Model 1 (resulting in Models 2 and 3), the fit of the model improved, as indicated by the lower AIC scores. The inclusion of personal travel variables did not alter the statistical significance of the relationship between eye-level greenery and PA among university students, although it did lead to slight alterations in the coefficients' magnitude (Model 1: Coef. = 0.288, S.E. = 0.068; Model 2: Coef. = 0.288, S.E. = 0.068; Model 3: Coef. = 0.278, S.E. = 0.065). In Models 2 and 3, a significant association emerged between personal travel characteristics and PA among university students. Specifically, the results of Model 2 revealed a positive association between owning a public transport pass and physical activity levels among university students (Coef. = 0.101, S.E. = 0.038). In Model 3, while controlling for all other variables, it was observed that walking significantly correlates with higher PA levels compared to driving (Coef. = 0.267, S.E. = 0.080). This model further highlights that active travel, a sustainable mode of transport, correlates with higher levels of PA among university students. Students who favoured active travel exhibited an increase of 0.162 units in their PA scores compared to those who did not have a preference for active travel. (Coef. = 0.162, S.E. = 0.039).

To further examine the impact of green space on varying intensities of physical activity (PA), we categorised PA into light (Model 3a), moderate (Model 3b), and vigorous (Model 3c) levels of activity, based on the best-fit model (Model 3), as shown in Table 3. According to Table 3, eye-level greenery demonstrated a statistically significant positive effect on all three PA intensity levels among university students, showing a stronger association with light (Coef. = 0.245, S.E. = 0.068) and moderate (Coef. = 0.247, S.E. = 0.063) activities than with vigorous activities (Coef. = 0.214, S.E. = 0.045). Additionally, the analysis also revealed statistically significant associations between a few personal travel characteristics (travel ability and travel mode) and moderate PA among university students, but no such associations were found for light or vigorous PA. Active travel was particularly strongly correlated with moderate (0.146-unit increase) and vigorous (0.187-unit increase) PA among university students, but no significant association was found with light PA.

Table 4 assessed the association between the NDVI, a green spatial metric derived from satellite imagery, and physical activity (PA) among university students by adapting Models 1–3 (designated as Models 1a-3a) to include NDVI as the independent variable, replacing eye-level greenery. The analysis revealed no statistically significant correlation between NDVI and PA across all three models ($p > 0.05$), in contrast with the significant associations that were identified between eye-level greenery and PA. Despite this, the relationships between personal travel characteristics (including travel patterns and active travel) and PA, which were significant in Models 1–3, persisted in Models 1a-3a.

3.3. Robustness tests

The robustness tests (Table 5) reaffirmed the findings from Table 3, except for the absence of a significant association between bus pass ownership and PA among university students in Model 4a and Model 4c. This inconsistency could potentially be attributed to variations in economic and living conditions influencing bus pass utilisation. Overall, the persistent correlations between other indicators and PA across various models, along with the stability of the coefficients, highlight the consistency and reliability of the findings.

Table 3
Multilevel regression results: Impact of GVI on different intensities of PA.

	Model 3a Coef. (S.E.)	Model 3b Coef. (S.E.)	Model 3c Coef. (S.E.)
Fixed Part			
Independent variables			
GVI	0.245**	0.247**	0.214**
	(0.068)	(0.063)	(0.045)
Covariates			
Demographic variables			
Female (ref: male)	0.033	0.037	0.012
	(0.042)	(0.043)	(0.056)
Age	0.003	−0.003	−0.001
	(0.004)	(0.004)	(0.006)
Educational Attainment (ref: undergraduate and below)			
Postgraduate and above	0.035	0.082	0.096
	(0.056)	(0.057)	(0.074)
Income (ref: Below 2000)			
2000–4000	−0.007	−0.049	−0.050
	(0.045)	(0.046)	(0.059)
Above 4000	0.066	−0.098	0.012
	(0.077)	(0.078)	(0.102)
Local hukou (ref: non-local)	−0.027	0.060	−0.032
	(0.043)	(0.043)	(0.056)
Partner relationship	0.009	0.012	0.047
	(0.045)	(0.045)	(0.059)
Transport abilities			
Driving licence	0.035	0.086*	0.011
	(0.043)	(0.043)	(0.056)
E-bike card	−0.063	0.005	−0.066
	(0.042)	(0.043)	(0.056)
Public transport card	0.012	0.107*	0.091
	(0.046)	(0.046)	(0.060)
Travel Mode			
Bus (ref: car)	0.081	0.136	−0.100
	(0.099)	(0.100)	(0.130)
Metro (ref: car)	0.028	0.090	−0.088
	(0.092)	(0.093)	(0.122)
Bike/e-bike (ref: car)	0.082	0.217*	−0.030
	(0.095)	(0.096)	(0.124)
Walking (ref: car)	0.139	0.440**	0.140
	(0.099)	(0.100)	(0.130)
Active travel	0.074	0.146**	0.187**
	(0.049)	(0.050)	(0.064)
Constant	−4.582**	−4.715**	−3.830**
	(1.179)	(1.089)	(0.793)
Random Part			
Var (Universities) (Estimate)	0.345*	0.292**	0.144*
	(0.156)	(0.133)	(0.069)
Var (Residual) (Estimate)	0.309**	0.316**	0.536**
	(0.015)	(0.016)	(0.027)
Number of individuals	811	725	674
Number of schools	10	10	10
AIC	1430.700	1446.300	1863.236

Note: * $p < 0.05$, ** $p < 0.01$.

4. Discussion

In this study, we explored the association between exposure to greenery and physical activity (PA) among Chinese university students using multilevel linear regression models, which included both eye-level greenery estimated using machine learning and vertical greenery calculated from remote sensing images. This study focused on university students due to the unique living conditions they experience on enclosed campuses and relatively high levels of PA, aspects which have been somewhat overlooked in previous research. The effect of travel patterns on PA was also taken into consideration. Our findings revealed that eye-level greenery within university campuses significantly enhances PA levels, which is in line with previous research [54], thus answering our first research question (RQ1). Taking the broader urban context into account, a study by Ferenchak and Barney [21] underscores that access to parks and green spaces significantly impacts public health through active transport networks, particularly for socio-economically

Table 4
Multilevel regression results: Impact of NDVI on PA.

	Model 1a Coef. (S.E.)	Model 2a Coef. (S.E.)	Model 3a Coef. (S.E.)
Fixed Part			
Independent variables			
NDVI	0.005 (0.003)	0.005 (0.003)	0.005 (0.003)
Covariates			
Demographic variables			
Female (ref: male)	0.034 (0.034)	0.034 (0.035)	0.031 (0.034)
Age	0.001 (0.004)	0.000 (0.004)	−0.001 (0.003)
Educational Attainment (ref: undergraduate and below)			
Postgraduate and above	0.078 (0.047)	0.086 (0.047)	0.089* (0.045)
Income (ref: Below 2000)			
2000–4000	−0.061 (0.037)	−0.055 (0.037)	−0.040 (0.036)
Above 4000	−0.046 (0.063)	−0.034 (0.064)	0.000 (0.062)
Local hukou (ref: non-local)	0.004 (0.035)	−0.009 (0.035)	−0.006 (0.034)
Partner relationship	0.017 (0.037)	0.014 (0.037)	0.030 (0.036)
Transport abilities			
Driving licence		0.035 (0.035)	0.046 (0.034)
E-bike card		−0.038 (0.035)	−0.052 (0.034)
Public transport card		0.101** (0.038)	0.085* (0.037)
Travel Mode			
Bus (ref: car)			0.031 (0.080)
Metro (ref: car)			0.002 (0.074)
Bike/e-bike (ref: car)			0.090 (0.076)
Walking (ref: car)			0.267** (0.080)
Active travel			0.162** (0.039)
Constant	−8.298 (4.289)	−8.302 (4.299)	−7.852 (4.198)
Random Part			
Var (Universities) (Estimate)	0.715* (0.322)	−0.719* (0.323)	0.685* (0.308)
Var (Residual) (Estimate)	0.218** (0.011)	0.216** (0.011)	0.200** (0.010)
Number of individuals	811	725	674
Number of schools	10	10	10
AIC	1144.393	1141.225	1087.846

Note: * $p < 0.05$, ** $p < 0.01$.

Table 5
Robustness tests.

	Model 4a Coef. (S.E.)	Model 4b Coef. (S.E.)	Model 4c Coef. (S.E.)
Independent variables			
GVI	0.291** (0.067)	0.276** (0.065)	0.277** (0.066)
Transport abilities			
Public transport card	0.079 (0.050)	0.08* (0.038)	0.056 (0.040)
Travel mode			
Walking (ref: cars)	0.220* (0.108)	0.256** (0.091)	0.293** (0.089)
Active travel	0.168** (0.054)	0.162** (0.041)	0.134** (0.042)
Number of individuals	811	725	674
Number of universities	10	10	10
AIC	1571.708	949.359	904.797

Note: * $p < 0.05$, ** $p < 0.01$.

disadvantaged groups, which parallels the findings in our study of university environments. Further analysis across different PA intensities (light, moderate, and vigorous) revealed positive associations for all three, albeit slightly weaker for vigorous PA. A possible explanation for the results is that a more pleasant environment could be created, depending on the time of year and how well maintained the plants are [44]. In summer, residents preferred areas shaded by trees and this led to an increase in PA. Nevertheless, while greenery at eye level showed a positive association, satellite-derived metrics were not found to be statistically linked to PA among university students, in contrast with Pasanen et al. [63] and Tsai et al. [72] 's findings. This outcome directly addresses our second research question (RQ2), indicating that eye-level greenery (or GVI) is more predictive of student PA than top-down measures such as NDVI. The broader NDVI metric does not fully capture perceived greenery from a human eye-level perspective, thus reinforcing the idea that visible, street-level vegetation shapes daily movement patterns. Moreover, individual demographic factors such as gender, age, and household registration (hukou) were found to have no significant influence on PA levels among university students, which aligns with the results reported by Koo et al. [43] in a study conducted in South Korea.

Our study fills a gap in previous research by offering insights into the PA status of Chinese university students who live in enclosed spaces for substantial periods of time. As demonstrated by Wolff et al. [78], spatial constraints and accessibility significantly shape individuals' perceptions and use of spaces, suggesting that students on enclosed campuses could exhibit comparable patterns of activity. It is likely that the enclosed nature of these campuses, combined with students' daily routines, influences their physical activity in similar ways to other constrained environments. Given that the study population consists of young adults in their 20s, it is crucial to recognise that their PA patterns may diverge from those of other age groups [20]. Our findings indicate that Chinese university students generally exhibit higher levels of PA compared to the PA energy expenditure of adults [39] and older people [84]. Additionally, our study explored the link between individual travel characteristics and PA levels among these students. Our findings suggest that approximately two-thirds of respondents were found to favour active travel, which is most likely influenced by the restricted access to other transport modes due to living on enclosed campuses [70], such as public transport and taxis. Furthermore, our study demonstrated that students inclined towards active travel tend to engage more in moderate and vigorous PA, such as cycling and walking. This finding supports the established connection between eye-level greenery and PA, including activities such as cycling [25] and walking [55], which is also true for other demographic groups, including older individuals [33].

The findings of this study have substantial implications for health-oriented urban planning. Given the limited research on how university students utilise green spaces, our results offer valuable insights for future urban landscape designs and planning efforts. A key policy recommendation from our analysis is the significant potential to foster PA among university students through the enhancement of visible greenery. According to a study conducted with 384 teenagers aged 13–19 in Aydın, Turkey, barriers to adolescents' physical activity in urban green spaces include a lack of greenness, distance to Urban Greening Systems, and concerns about safety and accessibility [2]. Therefore, considering the observed positive correlation between eye-level greenery and PA, universities should prioritise the enhancement of visual greenery within their campus environments. This can be achieved by planting trees, shrubs and other vegetation at a level that is easily visible, for example, along major pedestrian paths, as well as maintaining existing vegetation to ensure its health and visibility. Moreover, a study by Forde et al. [23] on alley greening underscores another dimension of urban green spaces, illustrating how transforming underutilised urban areas into greened alleys can significantly enhance community resilience, as was particularly noted during the COVID-19 pandemic. This aligns with our findings that visible greenery positively impacts public health and social interactions. In addition, the importance of accessibility to green space has been emphasised in relation to green space implementation and development on a global scale [48], leading to the introduction of guidelines by various countries, including many in Europe and Asia. It is also recommended that the Green View Index (GVI) could be used as an indicator to measure greenery in other metropolitan areas. For example, the city of Kyoto, in Japan, has adopted Green Vegetation Ratio (an indicator similar to GVI) as guidline for its urban greening systems [61]. However, designers should recognise that reference indicators may differ in relation to different urban environments. Creating a more supportive environment for PA will contribute to healthier living within the wider community.

Another crucial insight from our study is the importance of integrating the concept of active travel into the design of urban green spaces. Urban green spaces should transcend their traditional roles of comfort and environmental sustenance to actively foster PA. Features such as higher street density, greater diversity, and larger community size promote active travel, and local authorities should therefore support this by developing infrastructure that accommodates walking and cycling, such as urban greenways, and implementing incentives such as bike-sharing schemes [57]. In the case of green spaces, the planning of the HEMC potentially aligns with the goals of the *Healthy China 2030* initiative. Although the plan was released in 2015, a year earlier than the initiative, it had already stipulated that green space should comprise no <45 % of the total land area [27], demonstrating an early commitment to urban environments that promote health. However, it should be noted that market-oriented regulations and unbalanced policy-making can have adverse effects [13]. Urban planning policies that only focus on land use and ignore human well-being can exacerbate health and social inequalities. It is therefore crucial to ensure that planning policies prioritise human well-being and social equity in relation to sustainable urban development.

5. Limitations

We have identified five main limitations in relation to this study. Firstly, the IPAQ scale used in the survey did not accurately record the location of the physical activity, potentially overestimating on-campus PA due to a lack of specific location data. Secondly, our study lacked detailed data on the quality of green spaces, including individual preferences and types of vegetation, which might have elucidated the relationship between tree canopy and physical activity more effectively [22]. Thirdly, there was a time lapse between the street-view data being obtained and the collection of the survey data. In addition, this study acknowledges the difference between the spatial scale of green space exposure (aggregated GVI) and the individual-level survey responses. Although multilevel modelling helps to accommodate this difference, future research could further improve upon this by integrating spatiotemporally matched exposure data at the individual level using wearable or mobile sensing technologies. Lastly, this study focused only on the immediate impacts of green spaces on physical activity. Further research should explore the deeper mechanisms by which green space characteristics, such as vegetation type and density, affect physical activity levels.

6. Conclusion

Urban green spaces play a crucial role in promoting active lifestyles among urban residents, thereby positively impacting public health. In this study, we investigated how physical activity among university students on enclosed campuses is influenced by eye-level greenery and individual travel characteristics, using street-view imagery combined with survey data. The findings revealed a positive correlation between eye-level greenery and increased physical activity among university students, who were more active compared to the general population. Furthermore, an inclination towards active travel significantly influenced students' physical activity, highlighting the potential for greening strategies and pedestrian-friendly design to foster daily movement in enclosed environments. Given the specificity of enclosed campuses, local administrators and planners should implement targeted strategies, such as adding plants, shrubs and trees along the main pedestrian routes, enhancing accessibility to green spaces, and developing supportive cycling and walking infrastructure, to maximise these health benefits. This study also demonstrated that the Green View Index (GVI) can serve as a useful indicator to promote walking and cycling, enabling local authorities to systematically enhance both greenness and active mobility. This study enhances our understanding of how urban green spaces, active travel, and public health intersect, underscoring the broader potential of campus planning to foster active lifestyles.

CRediT authorship contribution statement

Yihang Bai: Writing – original draft, Visualization, Validation, Software, Resources, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. **Mengqiu Cao:** Writing – original draft, Validation, Supervision, Resources, Project administration, Methodology, Investigation, Formal analysis, Conceptualization. **Yiwei Bai:** Writing – review & editing, Resources, Investigation, Data curation. **Kaihan Zhang:** Writing – review & editing, Resources. **Xinyao Song:** Writing – review & editing, Resources. **Ruoyu Wang:** Writing – review & editing, Validation, Methodology, Conceptualization.

Declaration of competing interest

The author is an Editorial Board Member/Editor-in-Chief/Associate Editor/Guest Editor for this journal and was not involved in the editorial review or the decision to publish this article.

Data availability

The authors do not have permission to share data.

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