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Effects of neighborhood environment on different aspects of greenway use: Evidence from East Lake Greenway, China

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ABSTRACT

As a component of both urban transport infrastructures and green spaces, urban greenways play a vital role in connecting urban public spaces, promoting active travel, and facilitating population-level health outcomes. Recently, there has been considerable interest in illustrating the determinants of greenway use in various contexts. Nevertheless, most studies have failed to identify the different aspects of greenway use. Meanwhile, the potential significance of residential neighborhood environments in utilizing greenways has largely been overlooked. In this study, we analyzed data collected from 1020 residents living around the East Lake Greenway in Wuhan, China, to discern three aspects of greenway use: frequency, time, and intensity. In addition, we investigated the moderate effect of neighborhood environmental characteristics on the association between greenway proximity and different aspects of use. After controlling for covariates, multi-level regression models showed that greenway proximity and neighborhood environmental characteristics were significantly associated with greenway use, while the specific associations varied across different aspects of greenway use. Furthermore, proportion of residential land, floor area ratio, and street connectivity moderated the relationship between greenway proximity and greenway use. In summary, the findings of this study contributed to the planning and management of greenways in high-density cities.

1. Introduction

With rapid urbanization over the last four decades, approximately 65% of the Chinese population resided in urban areas in 2021. This unprecedented urbanization process has substantially changed the morphology and configuration of urban environments in China (Gong et al., 2012). For instance, numerous natural spaces in cities have been replaced by concrete and nonporous surfaces, and the deterioration of green spaces has influenced the performance of urban ecosystem services (Chen and Wang, 2013). Meanwhile, the prevalence of sedentary occupations and fast-paced lifestyles has led to a decline in physical activity levels among urban residents. This can trigger different chronic diseases, such as cardiovascular diseases, obesity, and some types of cancers (Cecchini et al., 2010). Therefore, using synthetic approaches to improve physical activity levels has become a public health priority for policymakers (Hunter et al., 2015). The creation of active transport infrastructure (e.g., walking trails and greenways) is considered one of the most cost-effective approaches for stimulating active travel and recreational physical activity levels (Senes et al., 2017).

As an indispensable type of urban green space, urban greenways are typically defined as linear and easily accessible green spaces established along natural corridors or converted roadways for recreational use (Akpinar, 2016). Over the past a few decades, numerous greenway projects have been planned and launched in various countries owing to their potential social, environmental, and health benefits (Liu et al., 2018). In China, implementing greenway development has become a key strategy for achieving the national goals of sustainable urbanism and improving the population-level physical activity (Zhang et al., 2020a). By 2016, over 160 cities had planned or implemented greenway projects, creating a total greenway length of 12,500 km (Liu et al.,

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2019). Despite the popularity and magnitude of investments, only a quarter of newly constructed greenways supported the daily activities of residents, resulting in the inefficient use of resources (Liu et al., 2016). Therefore, more research is needed to investigate the determinants of greenway use and to provide planning and design strategies to improve greenway use.

Based on socio-ecological model, green space use is affected by many aspects of factors, including green space features, individual characteristics, and environmental factors near greenways (Paneerchelvam et al., 2020). Specifically, key green space features include size, proximity, the presence of amenities, and the aesthetic value (Chen et al., 2017; Coutts and Miles, 2011). Regarding individual characteristics, gender, age, socio-economic status (SES), educational attainment, and travel mode are important for green space use (Wendel et al., 2012). In addition, features of the area surrounding greenways may also influence motivations of individuals to visit there, such as land use patterns, population density, and access to public transit (Honold et al., 2016; Keith et al., 2018).

Although prior studies have provided some insights, several obstacles prevent us from fully understanding the mechanisms of urban green space use, especially for greenways. First, the potential effects of residential neighborhoods are understudied, and incorporating neighborhood environments into analyses may aid in gaining a comprehensive understanding of the determinants of greenway use. Second, despite the fact that green space proximity affects green space use (Rossi et al., 2015), it seems that specific catchment areas vary in different environments. Therefore, it is possible the effect of green space proximity on green space use is moderated by built environment features of potential users' neighborhood. Third, there are various aspects of green space use, each of which reveals unique insights (Paneerchelvam et al., 2020). Prior studies predominantly adopted a single indicator (e.g., time or frequency), while comparing different aspects of greenway use and their determinants received limited consideration. Moreover, current indicators fail to provide clarity regarding the fulfillment of health benefits.

This study aims to investigate three research questions based on a newly developed large-scale greenway in Wuhan, China. First, whether the residential built environment influences greenway use? Second, whether distinct mechanisms exist for different aspects of greenway use? Third, how residential neighborhood environmental features moderate the effects of proximity on greenway use? The findings of this study could assist greenway planning and modification in densely populated urban areas.

2. Literature review and analytical framework

2.1. Green space use and its determinants

Urban green spaces (e.g., parks, greenways, and green gardens) provide abundant benefits to urban residents and enhance their quality of life (He et al., 2022b; Keith et al., 2018; Liu et al., 2022). Given the fact that contact and interaction with green spaces are prerequisite for obtaining the benefits from green spaces, considerable attention has been paid to unraveling the green space use patterns of residents and the potential determinants thereof (Akpinar, 2016; Liu et al., 2019). It is crucial for researchers and practitioners to investigate why some green spaces are more frequently used than others, as well as the triggering factors for their use. If specific green space characteristics fulfill the demands of residents, then modifying them could result in increased use. Numerous studies have summarized different types of factors that shape urban green space use based on recent research (Paneerchelvam et al., 2020).

Based on socio-ecological model, investigations into green space features, individual characteristics, and environmental factors in the areas surrounding greenways are essential in supporting or constraining greenway use (Paneerchelvam et al., 2020). Key green space features include size (Tamosiunas et al., 2014), green space proximity (Koohsari et al., 2013b), the presence of amenities (Sugiyama et al., 2014), and aesthetic value (Chen et al., 2017; Coutts and Miles, 2011). Although the magnitude of the effect varies with the context and population group (Wendel et al., 2012), good greenway proximity, as measured by straight-line or street-network distance between a residence area and a green space, tends to trigger more green space use (Akpinar, 2016). The underlying logic is that greenway proximity influences travel expenditures and travel duration to the green space (Koohsari et al., 2013a). Meanwhile, greenways that are crowded, unsafe, and poorly maintained are less likely to be visited (Boone et al., 2009). In addition, the aesthetic qualities of a greenway also affect its use by increasing or decreasing attractiveness (Goličnik and Thompson, 2010).

Gender, age, SES, educational attainment, and travel mode are important determinants of green space use (Wendel et al., 2012). Women are less likely to visit greenways owing to safety concerns, especially those greenways that are in a poorly maintained state. Socially disadvantaged groups (e.g., low-income and minority groups) tend to reside in neighborhoods further away from greenways and are therefore less likely to visit green spaces (Paneerchelvam et al., 2020). Highly-educated respondents are more inclined to visit green spaces because of their positive attitudes towards a healthy lifestyle (Shan, 2014). Respondents with better health and a preference for active travel modes are more likely to use green spaces (Paneerchelvam et al., 2020). In addition, environmental features around greenways are crucial in determining green space use, and the motivations of individuals to visit green spaces may be affected by land use patterns, population density, and availability of public transit (Honold et al., 2016; Keith et al., 2018). For instance, the availability of green spaces near a greenway may discourage residents to use this greenway because people may use nearby green spaces instead, whereas a high population density may increase greenway use due to high demand (Liu et al., 2018).

2.2. Different aspects of green space use

Although the underlying determinants that shape greenspace use have been investigated, consensus has not been reached regarding the definitions of greenway use. Different approaches have been adopted, such as conducting on-site interviews, estimating pedestrian volumes, and surveying representative respondents in surrounding neighborhoods (Liu et al., 2018). Since both use patterns and individual characteristics are embodied in questionnaires, surveying has been a prevalent approach to investigate green space use (Paneerchelvam et al., 2020).

In terms of survey-based studies, the frequency and time of green space use are two common metrics that represent distinct behavioral patterns. The frequency of greenway use refers to the number of times urban residents visit a particular green space within a given timeframe. In contrast, green space use times is a more comprehensive indicator, which is typically defined as the average duration of each visit multiplied by the visit frequency during a specific interval. They reflect different use information because time flexibility and incentive for leisure activities vary among individuals. Improving either of these aspects of greenway use may improve infrastructure operating efficiency and population-level health benefits. For instance, because weekdays offer less leisure time (Jim and Chen, 2008), highly educated users tend to engage in intensive recreational activities during their leisure time on weekends. Therefore, these users may visit green spaces less frequently but for longer durations. In contrast, poorly educated respondents were more likely to access green spaces during their lunch breaks on weekdays (Scott, 1997). However, most studies failed to simultaneously measure and assess the determinants of use time and frequency with a few exceptions (Chen et al., 2017). Akpinar (2016) found that greenway proximity is essential for determining both the use frequency and time, while facilities that are present have distinct effects on the frequency and time of greenway use. To summarize, it is important to further investigate the distinct mechanisms that determine the various aspects of greenway use.

2.3. *Potential influence of the residential neighborhood environment*

Prior studies investigating the environmental determinants of greenway use predominantly focused on the venues adjacent to greenways, whereas the potential effects of the residential environment were largely neglected. The underlying logic is that, as an important setting for daily activities, the residential environment may trigger or constrain the recreational activity decision-making of residents (Liu et al., 2022). First, it is believed that the residential built environment affects the motivation and willingness of individuals to visit public green space. For instance, if there is sufficient green space in the neighborhood, the propensity to use public green spaces (e.g., greenways) outside the neighborhood would decrease (Liu et al., 2018). Residents may have limited access to public spaces in neighborhoods with a higher population density. A higher degree of mixed land use in an area promotes everyday active travel, which simultaneously trigger more greenway use (Xie et al., 2022). Moreover, walkable residential environments (e.g., connective streets) may facilitate access to a greenway, thereby increasing its use (Shan, 2014). Second, stable and harmonious social environment is believed to play a fundamental role in encouraging greenway use (Paneerchelvam et al., 2020). Specifically, SES and social cohesion refer to the security conditions of the neighborhood, and safety concerns may discourage the use of public spaces. Meanwhile, higher social cohesion in neighborhoods could strengthen social bonds between neighbors and encourage them to visit green spaces together (De Vries et al., 2013).

In addition to the direct effects, the complex interactions between the built environment features and greenway use merit further scrutiny. Theoretically, the effect of proximity on greenway use was not constant and may depend on certain neighborhood types and environmental features (Paneerchelvam et al., 2020). For instance, it was assumed that neighborhoods with limited green space and a higher proportion of residential land would encourage residents to large-scale public green spaces (e.g., country parks and greenways). The rationale was that residents are compelled to travel farther to contact with nature if limited green space was provided nearby (Zhang et al., 2020b). Similarly, residents of densely populated neighborhoods were keen on vast green spaces to escape the crowded living environments. In addition, if the neighborhood has a connective street network, both perceived and actual barriers of travelling to green spaces would be alleviated.

2.4. *Our study*

We proposed an analytical framework for investigating the determinants of greenway use (Fig. 1). Except for the greenway proximity, the potential impact of greenway features (e.g., size, landscape, and amenities) on the greenway use could be ruled out, because these features would be identical for all users of this greenway. Therefore, the use of a greenway was determined by three categories of factors: individual characteristics, greenway proximity, and residential neighborhood environment. Neighborhood environmental attributes may also interact with greenway proximity and jointly shape greenway use. Furthermore, we extended and incorporated different indicators to measure greenway use (e.g., visiting frequency, time, and intensity), referring to both the operational efficiency of greenways and their potential health benefits.

3. Data and method

3.1. *Study area*

This study focused on the East Lake (*Donghu*) Greenway and surrounding areas in Wuhan. In 2019, over 11 million people resided in Wuhan, a densely populated city in central China (Wuhan Municipal Statistics Bureau, 2020). The East Lake, located in the metropolitan center, is the largest urban lake in China. To improve the performance of ecosystem services and promote public health, the local government converted a arterial road surrounding the lake into a traffic-free greenway with a total length of 110 km (He et al., 2022a). In 2017, this greenway was completed and made free access to the public. Upon completion of this project, many scenic areas (e.g., forests, wetlands, and historical sites) surrounding the lake were linked (He et al., 2021). As anticipated, this prominent greenway was praised by both experts and the public. The project was designated as the pilot project for

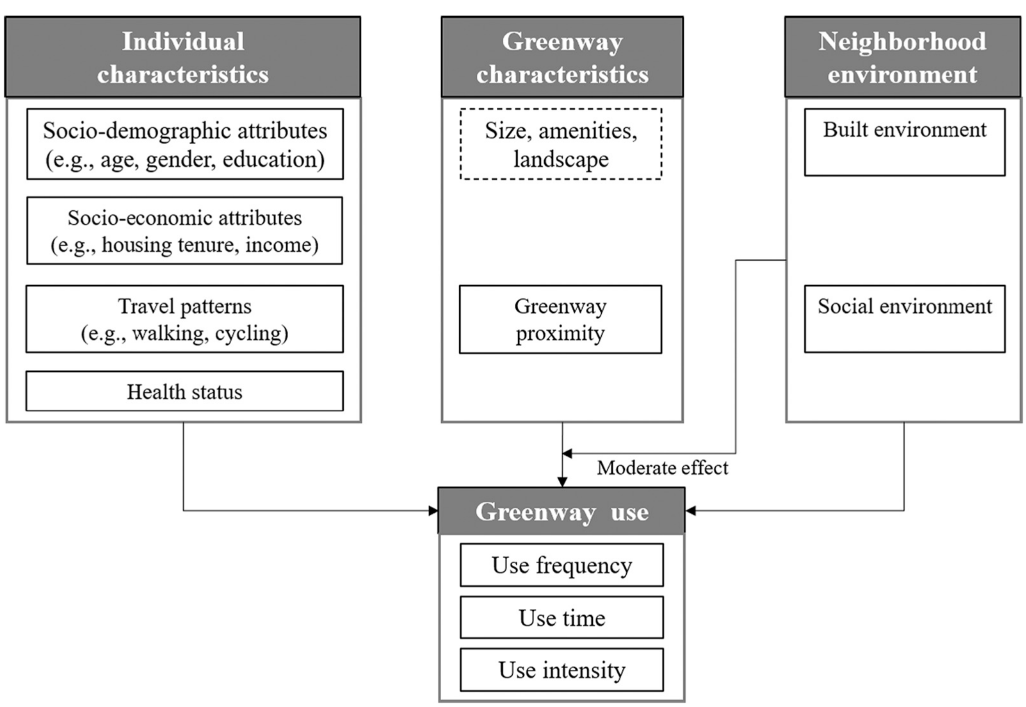

Fig. 1. Analysis framework of this study (we examined independent variables with solid lines).

improved urban spaces in China by UN-Habitat. It attracted 20.4 million visitors in 2018 and 72% of them were locals.

The research team conducted a longitudinal survey to examine the health benefits of the greenway project for nearby residents (Xie et al., 2021). Two waves of data were collected before and after the intervention in 2016 and 2019, respectively. This study was based on the follow-up survey (in April 2019). Notably, the pleasant springtime weather and suitable temperatures provided desirable conditions for nearby inhabitants to visit greenway. Regarding the survey design, a three-stage stratified sampling method was used to sample participants. First, potential users in different areas were surveyed because the intensity and patterns of greenway use may vary considerably between greenway segments (Lindsey et al., 2006). Three primary entrances that serve local residents were selected, and street-network buffers of 0–1 km, 1–2 km, 2–3 km, 3–4 km, and 4–5 km were created from each entrance to the greenway (Fig. 2). A 5 km distance threshold was adopted because, according to the planning criteria, city-level urban greenways in China are expected to have catchment areas of 5 km (Liu et al., 2016). Second, based on average property values, estates with approximately equal numbers of high-SES and low-SES groups were selected. Consequently, 52 housing estates were sampled. Third, participants (over the age of 18) from each estate were randomly selected based on the proportion of the total population of the estate. Face-to-face and structured interviews were conducted by qualified research assistants, and respondents who satisfactorily completed the questionnaire received gifts worth CNY 100–200. In total, the research team obtained data from 1020 valid respondents.

3.2. Measurement

3.2.1. Defining greenway use

In this study, the use of the East Lake Greenway by respondents was measured by three indicators: frequency, time, and intensity. The frequency of greenway use was measured using the self-reported frequency of visits by residents to this greenway over the past year. The scale was measured from 0 to 4, with a larger number indicating a higher frequency. Daily users of the greenway were categorized as the high-frequency group (high frequency = 4). If respondents used the greenway 1–6 times per week, they were classified as belonging to the mid-high frequency group (mid-high frequency = 3). Similarly, respondents who used the greenway 1–4 times per month were defined as the medium frequency group (medium frequency = 2). Respondents who used this greenway 1–11 times in the past year were categorized as the mid-low frequency group (mid-low frequency = 1). Those respondents who had never used this greenway in the past year were classified into the low-frequency group (low frequency = 0).

In the survey, respondents were asked to report the weekly time spent engaging in moderate physical activity, vigorous physical activity, walking, and sedentary behavior when using the East Lake Greenway. We then considered the aggregated weekly duration in the greenway as

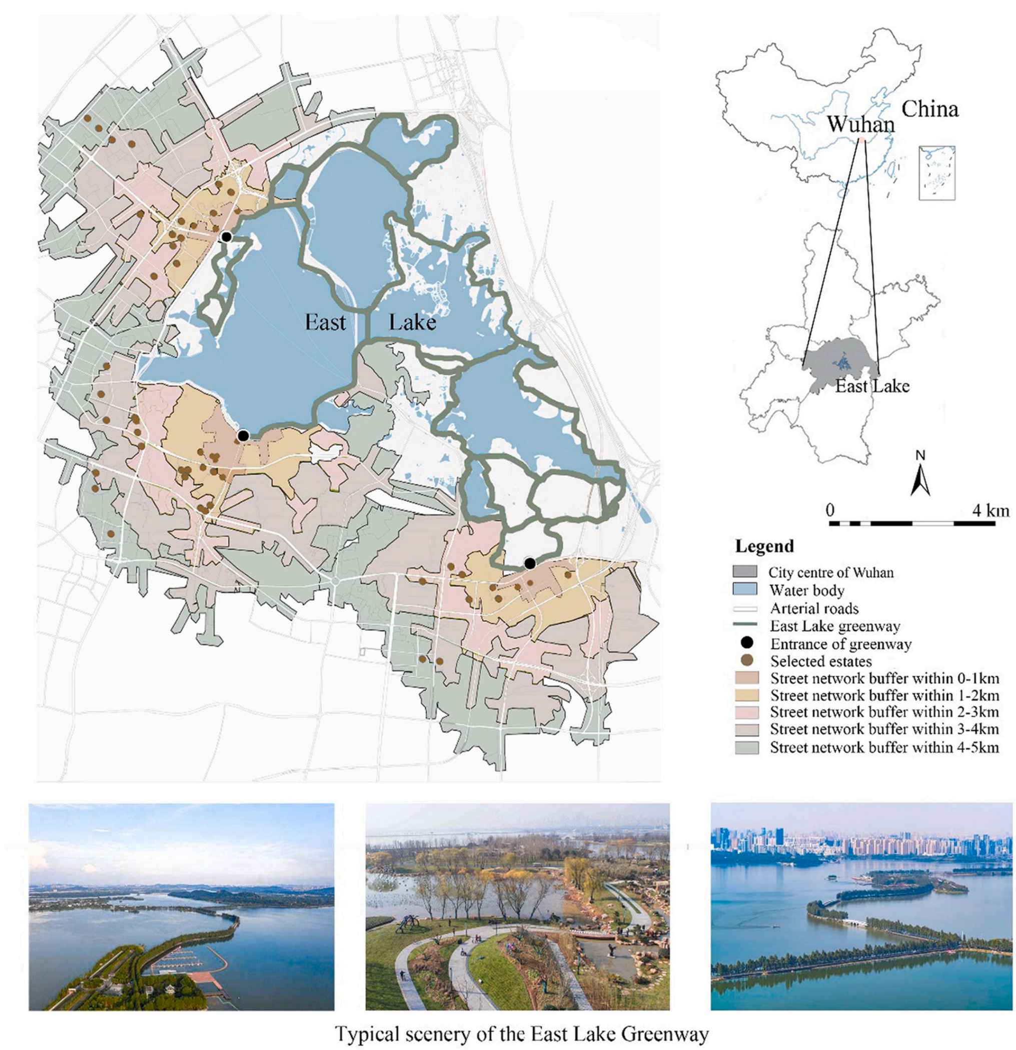

Fig. 2. Study area and sampled estates.

the use time.

In addition, we created a new variable: greenway use intensity. The World Health Organization (WHO) recommends 150 min of physical activity per week in order to maintain optimum health (Bull et al., 2020). This indicator was developed to assess whether greenway infrastructure fostered healthy amounts of weekly physical activity. Based on this criterion, a dummy variable was created. Greenway use intensity was deemed high when the weekly use time approached or exceeded 150 min. Otherwise, the rest of respondents were categorized into the low greenway use intensity group.

3.2.2. Greenway proximity

Using the street network analysis provided by Baidu Maps (https://map.baidu.com), the walking distance from the entrance of each estate to the nearest entrance of the East Lake Greenway was used to calculate the greenway proximity. Walking distance was preferred over straight-line distance because it more accurately reflected the travel time and level of physical effort required to reach the greenway.

3.2.3. Neighborhood environmental features

Residential neighborhoods were defined and assessed using a street-network buffer (500 m radius) centered on each housing estate. Based on the “5D” framework (Ewing and Cervero, 2010), we collected several features of the built environment. The land-use diversity was measured using Shannon’s diversity index, which indicates heterogeneity in the distribution of seven land-use types (e.g., commercial, residential, and office) (Xie et al., 2019). A higher value indicates greater land-use mix. The floor area ratio was calculated by dividing the total floor area of all buildings by the area of the neighborhood (He et al., 2021). The number of road intersections was calculated according to junctions of three or more street segments. All neighborhood environment datasets were provided by the local urban planning authority and obtained in 2019.

We also used several indicators to depict neighborhood social environments, including social interaction frequency, social cohesion, and neighborhood SES. Specifically, social interaction frequency and social cohesion were initially determined via individual surveys, and then average values were aggregated at the neighborhood level. Social cohesion was measured using the widely used 5-scale items of informal social control (Sampson et al., 1997), with a higher value representing a greater level of social cohesion (Cronbach’s alpha = 0.78). The social interaction level is a dichotomous variable referring to the average frequency of neighbor visits over the past year. If respondents interacted with their neighbors more than three times per week, a high value was assigned; otherwise, a low value was assigned. We used the average value of each estate to indicate the social cohesion of the neighborhood. In addition, SES was represented by the average estate-level property value. During the survey period, the average house price in the urban center of Wuhan was approximately CNY 20,000/m^2 (Xie et al., 2021). Thus, we used a value of CNY 20,000/m^2 as a threshold to identify high-SES neighborhoods.

3.2.4. Individual covariates

We adjusted for several demographic and socio-economic covariates and travel modes to the greenway. Age was a continuous variable. Gender (female vs. male), marital status (married vs. others), employment status (employed vs. others), number of household members (e.g., single-member household vs. others), and homeownership (owned vs. rent) were dichotomous variables. Educational attainment was categorized as college or higher against all other education levels. In addition, the annual household income was transformed using the logarithmic function to conform to a normal distribution. Self-reported health conditions were also incorporated based on the 12-item Chinese Short-Form Health Survey (SF-12) (Lam et al., 2005), with a Cronbach’s alpha of 0.86. In addition, respondents described their common means of travel to this greenway, which included walking, cycling, public transit, and private vehicles.

3.3. Method

Based on the proposed conceptual framework, we aimed to use both multi-level linear (for the frequency and time of greenway use) and logistic regression models (for the intensity of greenway use) to estimate the effects of the determinants on various aspects of greenway use.

The functional form of the random intercept multi-level linear regression model was as follows: where Y_{ij} denoted greenway use frequency or time for individual i in estate j, X_{ij} denoted individual-level variables, and Z_j denoted property-level variables. The symbols α and β were the coefficients of the outcomes and μ_j was the random effect of unobserved factors operating at the estate level.

$$Y_{ij} = \beta_0 + \alpha X_{ij} + \beta Z_j + \gamma_c + \mu_j$$

In the multilevel logistic model, the functional form was as follows: where P_{ij} denoted the greenway use intensity probability P ($y_{ij} = 1$) for individual i in estate j, X_{ij} denoted individual-level variables, and Z_j denoted estate-level variables. The symbols α and β were the corresponding coefficients of the independent variables and μ_j was the random effect of unobserved factors operating at the estate level.

$$log\left(\frac{P_{ij}}{1 - P_{ij}}\right) = \beta_0 + \alpha X_{ij} + \beta Z_j + \mu_j$$

The intraclass correlation coefficient (ICC) indicator was employed to compute the ratio of variation between estates to the total variation. Multicollinearity among covariates was tested using variance inflation factors (VIF). For linear regression models, we supplied standardized regression coefficients and 95% confidence intervals. Regarding logistic models, we reported the odds ratios and 95% confidence intervals. All statistical analyses were performed using STATA 15.0.

4. Results

4.1. Descriptive results

As shown in Table 1, more than half of the participants were female (56.6%). The average age of the respondents was 50.8 years, and their annual log-transformed household income was 11.9 CNY. More than half of the respondents were employed and had attained a high level of education, and over 80% of respondents were married and homeowners. In addition, nearly half of the participants preferred walking to the greenway.

To examine and ensure the representativeness of the sampled respondents, we compared their fundamental characteristics to those of the overall population in the city center of Wuhan using census data. The results essentially confirmed that there were no significant disparities between the sampled respondents and the overall population, with the exception of annual household income (He et al., 2021). This was not

Table 1
Descriptive results of individual characteristics ($n = 1020$).

Variable	Mean (SD)/%
Individual characteristics	
Gender (female = 1)	56.6
Age	50.8 (16.0)
Employment status (yes = 1)	55.9
Marital status (married = 1)	83.5
Educational attainment (college or above = 1)	50.3
Annual household income (log transformed)	11.9 (0.9)
Homeownership (yes = 1)	81.7
Self-rated health status	102.0 (9.1)
Household member (single-member household =1)	18.3
Travel mode to the greenway	
Walking	49.3
Cycling	8.0
Public transit	8.5
Car	15.2

Table 2
Descriptive results of neighborhood environmental characteristics ($n = 52$).

Neighborhood environmental characteristics	Mean (SD)
Greenway attributes	
Walking distance to the nearest greenway entrance (m)	1618.2 (1124.8)
Neighborhood built environment	
Floor area ratio	1.1 (0.4)
Population density (per hectare)	201.1 (149.6)
Land-use mix	1.6 (0.3)
Street connectivity	7.3 (0.4)
Number of parks	0.1 (0.1)
Proportion of residential land (0–1)	0.4 (0.0)
Proportion of park land (0–1)	0.1 (0.1)
Neighborhood social environment	
Average social cohesion	16.3 (0.5)
Average social interaction	0.7 (0.1)
Neighborhood SES (log transformed) (CNY/m^2)	9.9 (0.2)

surprising, considering that housing prices near East Lake tend to be higher than average.

Table 2 shows the neighborhood-level environmental features. In particular, the average greenway proximity was 1618.2 m. The mean floor area ratio was 1.1, and the average population density was 201.1 individuals per ha. In terms of land-use patterns, the mean land-use mix index was 1.6, and proportion of residential and park land were 0.4 and 0.1, respectively. Regarding the neighborhood social environment, the average social cohesion and social interaction were 16.3 and 0.7, respectively. In addition, the log-transformed neighborhood SES (average housing price per square meter) was 9.9.

4.2. Main results

Table 3 depicts the coefficient estimates of the potential factors affecting different aspects of greenway use. Multi-level regression models were appropriate for this dataset (ICC > 0.1), and there were no serious issues with multicollinearity (VIF < 2). Self-rated health (0.53, $p < 0.05$) was positively associated with greenway use frequency, whereas homeownership (−0.12, $p < 0.05$) and single-member household (−0.16, $p < 0.10$) were negatively associated with greenway use frequency. Regarding travel mode, walking (0.72, $p < 0.01$) and cycling (0.51, $p < 0.01$) to the greenway were positively associated with greenway use frequency. As expected, greenway proximity (−0.12, $p < 0.01$) was negatively associated with greenway use frequency. Regarding neighborhood attributes, social cohesion was positively associated with greenway use frequency (2.62, $p < 0.10$).

In terms of greenway use time (Model 2), several individual attributes were significant. Specifically, female (−0.11, $p < 0.05$) and less educated (0.10, $p < 0.05$) respondents tended to experience less greenway use time, while older (0.01, $p < 0.05$) respondents tended to have higher greenway use time. In contrast to travelling by cars, walking to the greenway (0.25, $p < 0.01$) and using public transit (0.18, $p < 0.10$) were positively associated with greenway use time. In addition, the floor area ratio was negatively associated with greenway use time (−0.17, $p < 0.10$). Unexpectedly, good greenway proximity did not show a significant association with greenway use time.

Regarding greenway use intensity (Model 3), greenway proximity (OR = 0.73, $p < 0.05$) was negatively associated with greenway use intensity. Age (OR = 1.01, $p < 0.05$), walking (OR = 6.28, $p < 0.01$), and cycling (OR = 2.75, $p < 0.01$) were positively associated with greenway use intensity. Regarding neighborhood attributes, the floor area ratio (OR = 0.28, $p < 0.05$) was negatively associated with greenway use intensity.

4.3. Moderate effects

We developed three additional models to investigate the complex interactions of neighborhood environmental features in determining different greenway uses (Table 4, Model 4–6). Three interaction terms (Greenway proximity × floor area ratio, greenway proximity × proportion of residential land, and greenway proximity × street connectivity) were significantly associated with greenway use frequency. Meanwhile, two interaction items (greenway proximity × proportion of

Table 3
The association between different independent variables and three aspects of greenway use.

Dependent variable		Model 1 (use frequency)	Model 2 (use time)	Model 3 (use intensity)
		Coefficient (95% confidence interval)	Coefficient (95% confidence interval)	Odds ratio (95% confidence interval)
Greenway attributes	Greenway proximity	-0.12*** (-0.19- -0.05)	-0.02 (-0.08-0.04)	0.73** (0.54-0.98)
Individual attributes	Gender	0.01 (-0.07-0.08)	-0.11** (-0.20- -0.02)	0.90 (0.64-1.26)
	Age	-0.01 (-0.01-0.00)	0.01** (0.00-0.01)	1.01** (1.00-1.02)
	Employed	-0.02 (-0.10-0.06)	0.04 (-0.06-0.14)	0.89 (0.62-1.29)
	Marital status	0.06 (-0.07-0.19)	-0.09 (-0.24-0.07)	0.92 (0.52-1.62)
	Education attainment above)	0.05 (-0.03-0.14)	0.10** (0.00-0.20)	1.35 (0.94-1.94)
	Income	0.01 (-0.04-0.06)	-0.04 (-0.10-0.03)	0.88 (0.69-1.12)
	Homeownership	-0.12** (-0.22- -0.01)	-0.06 (-0.18-0.07)	0.74 (0.46-1.19)
	Single-member household	-0.16* (-0.33-0.02)	0.10 (-0.11-0.31)	1.08 (0.50-2.32)
	Self-rated health	0.53** (0.12-0.95)	0.13 (-0.37-0.63)	4.63 (0.63-33.85)
Travel mode	Walking	0.72*** (0.59-0.85)	0.25*** (0.10-0.40)	6.28*** (3.24-12.19)
	Cycling	0.51*** (0.34-0.67)	-0.07 (-0.27-0.12)	2.75*** (1.25-6.04)
	Public transit	0.06 (0.34-0.67)	0.18* (-0.03-0.39)	1.25 (0.46-3.41)
Neighbourhood built environment	Floor area ratio	-0.09 (-0.33-0.16)	-0.17* (-0.40-0.03)	0.28** (0.09-0.84)
	Population density	0.00 (-0.01-0.00)	0.00 (0.00-0.00)	1.00 (1.00-1.00)
	Land-use mix	-0.08 (-0.32-0.15)	-0.03 (-0.28-0.12)	1.76 (0.66-4.67)
	Proportion of park land	0.39 (-0.77-1.56)	4.94 (-1.08-0.93)	0.36 (0.01-20.15)
	Street connectivity	0.00 (-0.01-0.01)	0.00 (-0.01-0.01)	2.48 (0.27-22.8)
	Proportion of residential land	0.22 (-0.35-0.79)	-0.21 (-0.70-0.29)	1.00 (1.00-1.01)
Neighbourhood social environment	SES status	0.12 (-0.50-0.70)	-0.21 (-0.73-0.32)	2.66 (0.65-10.95)
	Social cohesion	2.62* (-0.15-5.19)	0.03 (-2.34-2.40)	1.30 (0.00-10.43)
	Social interaction	0.11 (-0.25-0.48)	0.11 (-0.22-0.44)	0.38 (0.04-4.09)
Constant		-8.94** (-17.22- -0.67)	3.64 (-3.90-11.19)	0.01* (0.00-5.10)
Log Likelihood		-930.85	-1108.77	-461.14
n		1020	1020	1020

Notes: 1) * $p < 0.1$, ** $p < 0.05$, ***$p < 0.01$.

Table 4
Moderate effect of different neighborhood environmental characteristics on the association between greenway proximity and greenway use.

Dependent variable		Model 4 (use frequency)	Model 5 (use time)	Model 6 (use intensity)
		Coefficient (95% confidence interval)	Coefficient (95% confidence interval)	Odds ratio (95% confidence interval)
Greenway attributes	Greenway proximity	-0.10** (-0.19- -0.02)	-0.02 (-0.11-0.07)	0.71* (0.48-1.07)
	Floor area ratio	0.01 (-0.24-0.26)	-0.23* (-0.48-0.02)	0.31*** (0.12-0.78)
	Population density	0.00 (-0.01-0.00)	0.00 (0.00-0.01)	1.00 (1.00-1.00)
Neighbourhood built environment	Land use mix	-0.34*** (-0.60-0.08)	-0.20 (-0.45-0.06)	0.89 (0.32-2.48)
	Proportion of park land	1.18 (-0.40-2.75)	0.11 (-1.55-1.77)	1.00 (0.00-62.71)
	Street connectivity	0.00 (-0.01-0.01)	0.00 (-0.01-0.01)	1.01*** (1.00-1.01)
	Proportion of residential land	0.20 (-0.34-0.73)	-0.21 (-0.72-0.31)	1.02** (1.00-1.04)
Interaction terms	Greenway proximity x floor area ratio	-0.30** (-0.58-0.02)	-0.07 (-0.35-0.22)	0.68 (0.23-2.04)
	Greenway proximity x population density	0.00 (0.00-0.00)	0.00 (-0.01-0.01)	1.00 (1.00-1.00)
	Greenway proximity x land-use mix	-0.10 (-0.26-0.06)	-0.14 (-0.31-0.03)	0.93 (0.35-2.50)
	Greenway proximity x proportion of residential land	0.59*** (0.19-0.98)	0.24 (-0.15-0.64)	1.20*** (0.62-1.82)
	Greenway proximity x street connectivity	0.01** (0.00-0.01)	0.00 (-0.01-0.01)	1.01** (1.00-1.01)
	Greenway proximity x proportion of park land	0.24 (0.19-0.98)	0.77 (-0.15-0.64)	1.07 (1.00-1.15)
Individual attributes		Yes	Yes	Yes
Constant		-5.79 (-13.65-2.07)	6.86* (-1.14-14.86)	0.00 (0.00-26.74)
Log Likelihood		-923.99	-1105.21	-451.09
n		1020	1020	1020

Notes: 1) * $p < 0.1$, ** $p < 0.05$, ***$p < 0.01$.

Table 5
The association between different independent variables and three aspects of greenway use (for the respondents whose residence was more than 500 m away from the nearest entrance of East Lake Greenway).

Dependent variable		Model 7 (use frequency)	Model 8 (use time)	Model 9 (use intensity)
		Coefficient (95% confidence interval)	Coefficient (95% confidence interval)	Odds ratio (95% confidence interval)
Greenway attributes	Greenway proximity	-0.09*** (-0.16- -0.03)	0.00 (-0.05-0.06)	0.86 (0.65-1.14)
	Floor area ratio	-0.06 (-0.01-0.00)	-0.16 (-0.36-0.05)	0.38* (0.13-1.06)
	Population density	0.00 (0.00-0.00)	0.00 (0.00-0.01)	1.00 (1.00-1.00)
	Land-use mix	-0.09 (-0.32-0.13)	-0.09 (-0.27-0.09)	1.97 (0.83-4.66)
	Proportion of park land	0.60 (-0.50-1.71)	0.09 (-0.84-1.01)	0.86 (0.0-26.12)
	Street connectivity	0.00 (0.00-0.01)	0.00 (-0.01-0.01)	1.00 (1.00-1.01)
Neighbourhood built environment	Proportion of residential land	0.43 (-0.12-0.99)	0.00 (-0.47-0.47)	1.02* (1.00-1.04)
	SES status	-0.04 (-0.62-0.54)	-0.21 (-0.84-0.14)	2.71 (0.62-11.93)
Neighbourhood social environment	Social cohesion	2.62* (-0.35-4.72)	0.03 (-2.54-1.80)	1.04 (1.00-1.08)
	Social interaction	0.15 (-0.24-0.55)	0.11 (-0.18-0.52)	0.22 (0.03-1.78)
Individual covariates		Yes	Yes	Yes
Constant		-8.52** (-16.65- -0.40)	4.17 (-3.02-11.35)	0.00* (0.00-116.78)
Log Likelihood		-903.46	-1037.20	-429.72
n		970	970	970

Notes: 1) * $p < 0.1$, ** $p < 0.05$, ***$p < 0.01$.

residential land, and greenway proximity × street connectivity) were significant for greenway use intensity.

4.4. Sensitivity analysis

The residential neighborhoods of several respondents were adjacent to the greenway. Therefore, several residential neighborhood environments may have resembled greenway environments. For the sensitivity analysis (Table 5), we excluded respondents whose residential neighborhood was less than 500 m from the nearest entrance to East Lake Greenway (final sample size = 970). The results appeared to be stable, with only minor changes observed in the associations.

5. Discussion

5.1. Main findings

Despite the growing popularity of greenway projects in China (Zhang et al., 2020a), numerous greenways were built in inappropriate locations or poorly maintained, preventing residents from using them and achieving the desired health benefits (Liu et al., 2018). This study investigated the determinants of three aspects of greenway use (i.e., frequency, time, and intensity of use) based on a newly developed large-scale greenway project in Wuhan, China.

The findings illustrated that individual attributes , greenway proximity, and the neighborhood environmental attributes were all important in predicting different aspects of greenway use and distinctive mechanisms were involved in determining greenway use. Specifically, greenway proximity was significant in predicting both greenway use frequency and intensity. For such a vast project, geographical distance affected the daily opportunities and motivations of individuals to visit and interact with greenways and achieve the recommended physical activity levels. East Lake Greenway provided scenery and recreational venues for nearby residents and improved the probability of obtaining long-term health benefits. In contrast, the duration of exposure may be determined by unobserved individual factors such as their flexibility of leisure time and preference. This result further extended previous evidence on green space proximity and use (Schipperijn et al., 2010).

Regarding residential built environment attributes, the neighborhood floor area ratio was negatively associated with greenway use time and intensity. The finding rejected our initial assumption. The neighborhoods with higher floor area ratios in Wuhan are likely to be modern housing estates, which provided well-maintained green spaces and recreational facilities within these estates (Xiao et al., 2016). Therefore, residents of these estates have less demanding to use green spaces outside their estates. In terms of the social environment, neighborhood social cohesion may influence the greenway use frequency. High levels of neighborhood social cohesion may lead to increased social interactions among neighbors. Therefore, the chances of visiting greenways together with friends and neighbors increases (Reynolds et al., 2007).

Furthermore, we observed the moderate effect of the residential built environment on the association between greenway proximity and different aspects of greenway use. A plausible explanation for the moderate effect of residential land was that a higher proportion of residential land is often linked to limited access to recreational spaces. Numerous old neighborhoods (*danwei*) in Wuhan were characterized by subsidized housing with narrow living spaces, limited green space, and old recreational facilities. Therefore, these neighborhoods deserved much attention in urban renewal projects (Xie et al., 2019). In densely populated neighborhoods, the lack of green space would be exacerbated, and residents would be compelled to routinely visit large-scale greenways to satisfy their daily needs, regardless of the distance. In terms of the effects of floor area ratio, it appeared that neighborhoods with higher floor area ratios were mostly modern estates, which predominantly offered well-maintained green space within the estates. In this regard, such green space may compensate for the shortage of public green space. In addition, neighborhoods with interconnected street networks were mostly walkable, and well-connected streets in residential neighborhoods improved travel experiences and shortened travel times to the greenway (Lindsey et al., 2008). The East Lake Greenway provided valuable opportunities for respondents to interact with nature, thereby attracted residents from these neighborhoods with limited green space. Therefore, the catchment areas for these types of neighborhoods were much greater than counterpart neighborhood types.

In addition, this study further extended our understanding of the importance of individual attributes on greenway use, including socio-demographic and socio-economic attributes, as well as travel modes to greenway. In contrast to the findings in Western settings (Reynolds et al., 2007), our results showed that female respondents were more likely to use greenway, possibly because of the safe environment created by the surrounding neighborhoods. Consistent with previous studies in China (Chen et al., 2017), we found that travel mode, family structure, and educational attainment were significant determinants for greenway use (Chen et al., 2017).

5.2. Policy implications

The findings of this study have several policy implications that may facilitate greenway management and aid in the optimization of greenways in high-density cities. First, given that greenway proximity affects several aspects of greenway use (e.g., frequency and intensity), the potential catchment areas and population served by new greenway projects should be a high priority during the design and planning phases. Since there are only three primary entrances to East Lake Greenway, additional entrances could be created to increase accessibility for nearby residents. Meanwhile, the street network connecting residential areas and the greenway should be meticulously planned to reduce travel distance and facilitate walking, thereby increasing greenway use. Second, it is recommended that policymakers pay more attention to neighborhoods that have a higher proportion of residential land use. When implementing urban renewal projects on these properties, it is also necessary to add more green spaces.

5.3. Strengths and limitations

This study contributes to the current literature by assessing the determinants of three aspects of greenway use and verifying the influence of the residential neighborhood environment. In addition, we investigated whether different neighborhood environmental features moderated the effects of greenway proximity on greenway use.

Several limitations of this study must be acknowledged. First, the study was based on self-reported frequency and duration of greenway use. We suggest that future studies should collect objective indicators using portable global positioning systems (Wu et al., 2022). Second, we failed to collect detailed behavioral patterns of greenway users. It is advocated that future studies should incorporate individual physical activities (e.g., jogging, cycling, and walking) and preferences into surveys. Third, although we accounted for social environment indicators, future studies could adopt more objective measures (e.g., crime rate).

6. Conclusion

This study investigated the determinants of three aspects of greenway use (frequency, time, and intensity) based on questionnaires collected from 1 020 residents residing near the East Lake Greenway in Wuhan, China. The results of multi-level regression models showed that greenway proximity and neighborhood environmental features were significantly associated with three aspects of greenway use, whereas specific associations varied across specific greenway use. Furthermore, higher proportion of residential land, floor area ratio, and street connectivity moderate the association between greenway proximity and greenway use.

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Ethics approval

Ethical approval for the study was obtained prior to this study from the Research Committee of City University of Hong Kong (No. H000691). All participants provided written informed consent.

Credit authorship contribution statement

Bo Xie: Conceptualization, Data Curation, Writing - review & editing. Zhe Pang: Methodology and analysis. Dongsheng He: Methodology, Visualization, Writing - Original Draft. Yi Lu: Conceptualization, Writing - review & editing. Yujie Chen: Methodology and analysis.

Declaration of Competing Interest

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

Data availability

The data that has been used is confidential.

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