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Research on the influence mechanism and optimisation of urban greenway network use pattern based on multi-source data - a case study of Guangzhou, China

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1. Abstract

Urban greenways have become the major venue for inhabitants to relax and exercise in recent years. The impact of non-motorised travel and urban recreation on greenways grows. So the primary purpose of improving and enhancing greenway design is to meet users' recreational and leisure demands. However, general greenway planning usually contrasts with actual resident use. More study is necessary to assess whether the efficiency of urban greenway use is compatible with planning goals. Using multiple source data to analyse urban dwellers' use patterns and the factors that impact them might provide a new perspective on designing and optimising greenways.

Using Guangzhou as an example, this paper investigates the use pattern of greenways and their spatial and temporal distribution characteristics based on the user movement trajectory data/ distribution map, identifies potential high-use sections of greenways, and then selects the factors affecting the use intensity of greenways, and performs spatial correlation analysis using the geographical detector. Finally, the weighting of different influencing factors provides a reasonable basis for the optimal construction and improvement of urban greenways.

2. Introduction

Due to the rapid development of technology and population growth, the stressful and oppressive city life has made it impossible for people to be well satisfied physically and psychologically. On the other hand, the emergence of greenways is gaining more and more attention as they provide opportunities for people to get close to nature, relax, and engage in outdoor activities.

Greenways are networks of land containing linear elements that are planned, designed, and managed for multiple purposes, including ecological, recreational, cultural, aesthetic, or other purposes compatible with the concept of sustainable land use (Ahern 1995). Many countries have established more mature greenway systems and related greenway facilities. In China, research on greenways began in 1985, and the practice of greenways has been promoted since 2000 (Hu and Dai 2010); in 2010, the Outline of the Master Plan for the Pearl River Delta Greenway Network was promulgated as a top-down, policy-oriented greenway planning project for the whole Guangdong province (Wang, Jin and Xu 2022). However, this approach to construction taken by policymakers is devoid of public input (Xu et al. 2020). As a result, the planning and practice of greenways carried out with such a limited grasp of the public interest is somewhat different from the demands of residents in terms of spatial matching, and the actual usage of greenways is still to be determined. Therefore, planners' perspectives must shift away from grand land policy and toward the fundamental subject of spatial use - the human scale - emphasising resolving the contradiction between individual wants and resource availability. Traditional data collection methods such as map markers and questionnaire surveys are commonly time-consuming and labour-intensive, limiting research to a small geographical scale; however, with the advancement of technology, the widespread use of big data has significantly increased the efficiency of research and consequently expanded its scope. Planners can collect human trajectories and mobility patterns using Big Data and use them to evaluate the rationale of geographical resource allocation and the virtues of spatial design.

Additionally, studying the built environment factors that influence the user behaviour of greenway populations is critical for increasing the efficiency of greenway spatial usage and establishing a foundation for future greenway route selection. However, previous research has concentrated on qualitative links or statistical relationships based on regression models. Thus, this paper introduces the geographical detector method as a quantitative research tool to examine the spatial correlation between the intensity of greenway use and potential influencing factors.

In summary, to carry out research on people's use of greenways in the urban built environment and its influence mechanism, this paper attempts to combine web crawler technology, analyse the movement trajectories of urban residents through Big Data, establish the use intensity model to evaluate residents' use of greenways, and quantitatively assess the influence of the surrounding built environment factors on the use pattern of urban greenways with the help of the geographical detector. Additionally, the degree of influence of various factors is used to determine the index weights in the greenway suitability assessment system, which provides a basis for the selection of urban greenway system construction and further route optimisation.

3. Background and Literature Review

In high-density urban environments, non-motorised travel and urban recreation in the function of greenways are gradually expanding owing to public desire for non-motorised transportation and open space (Liu, Wang and Zhao 2017). As the public becomes more involved in greenways, Post Occupancy Evaluation (POE) is being conducted, along with the accumulation of public feedback during the use process. The majority of studies have focused on the users' behaviour and presence on the greenway; the users of the greenway includes socioeconomic and demographic characteristics such as age, gender, and income level of the population (Frank, Hong and Ngo 2019); and the greenway's use behaviour includes use pattern, usage, time of use, and reasons for use (Liu et al. 2018; Keith et al. 2018). Among them, the greenway use pattern (Lindsey 1999; Liu et al. 2018;) is a valid indicator for measuring whether the supply of greenways matches public demand. However, several recent studies have recorded and transcribed spatial behaviour through the traditional methods of observational statistics, map markers and questionnaires (Larson et al. 2016), which are time-consuming and labour-intensive. Thus the research scale primarily focuses on finer scales such as key selected sections of greenways and lacks an evaluation of the spatial and temporal distribution of use across the entire greenway network.

Big Data is a new technology that facilitates the study of user behaviour and perception at the macro scale. One type of Big Data, known as User Generated Content (UGC), is defined as published content on a publicly accessible website or a social networking site displaying a certain amount of creative effort (Kaplan and Haenlein 2010). It has been widely utilised in the study of urban spatial use. The present UGC-assisted research on the use of public space focuses mainly on the spatial and temporal characteristics of users' recreation and their preferences and satisfaction. The former frequently employ Big Travel Data, trajectory data from sports apps, and social media punch card data (Liu and Lai 2019; Ding 2018; Wang and Ma 2020) to summarise and analyse trip patterns based on users' location, time, and activity state. While the latter use software with commentary capabilities to analyse patterns of recreational preferences among users based on their natural and social characteristics as provided by UGC (Zhao, Li and Zhao 2019). UGC data covers a wide range of areas and has a large sample size, and can be used in greenway research to visualise the needs of the population more objectively and scientifically, thus compensating for the shortcomings of traditional research methods in terms of insufficient sample size and specific errors due to subjective statistics.

Furthermore, since the end of the 20th century, to improve greenway alignment patterns and increase the efficiency of future greenway use, researchers have begun to explore the factors that influence greenway use, mainly including user characteristics, weather conditions, time variables and built environment (Coutts 2009; Böcker et al. 2015; Dill and Voros 2007; Senes et al . 2017), with the influence of built environment on usage behaviour being the most studied topic (Coutts 2008; Baltes 1996; Chatman 2009; Boarnet, Greenwald and McMillan 2008) and the only factor that can be enhanced and improved through planning and construction. The quantitative analysis of the built environment is primarily based on the 5D theory system, which consists of five dimensions: density, diversity, design, destination accessibility, and distance to transit (Cervero and Day 2008; Ewing et al. 2015). By using the 5D indicators, studies have been conducted to examine the impact of the built environment on pedestrian commuting, residents' leisure activities, individual health levels, and residential satisfaction (Sun and Yin 2018; Sung and Lee 2015), while other researchers have examined the impact on greenway use using single or several indicators from the 5D method, such as accessibility, population density, land use, and land mix factors, with confirmed a positive association (Akpinar 2016; Lindsey 1999; Song, Merlin and Rodriguez 2013; Rodriguez et al. 2009; Larson et al. 2016). As a result, the 5D method was chosen to investigate the effect of the built environment on greenway use, which would aid in the planning and design of future greenways and provide quantitative and scientific decision support for planning managers.

In terms of correlation analysis between greenway use and built environment factors, past research has relied on non-spatial statistical approaches and regression analysis, focusing mainly on mathematical-statistical relationships and disregarding spatial influence. As a spatial statistical model, the geographical detector (Wang and Xu 2017) can explore the impact of geographic parameters on spatial differentiation. This method has been widely used to investigate the mechanism by which the natural ecological or socioeconomic environment influences a factor and has been gradually applied to the study of travel behaviour or transportation research to explore the influence of environmental factors on usage behaviour (Wang, Meng and Feng 2022), thus becoming the primary research method for this paper.

Method and Data

Study area

Guangzhou is located in the south-central region of Guangdong Province (112°57′E-114°3′E, 22°26′-23°56′N) and is one of the core cities of the Pearl River Delta (PRD) urban agglomeration. Guangzhou is divided into 11 municipal districts: Yuexiu District, Liwan District, Baiyun District, Haizhu District, Tianhe District, Huangpu District, Panyu District, Huadu District, Nansha District, Zengcheng District, and Conghua District, and the total area of Guangzhou is 7434.4 $km^{2,}$ and the resident population is 18,676,600. As part of the Pearl River Delta greenway, the Guangzhou greenway was planned in 2010 and gradually completed from 2011 to 2013. In Guangzhou, 3,565 kilometres of greenways have been completed, with an average density of 0.48 km^2. The highest density of greenway distribution is in Haizhu District at 2.16 km/km^2, while the lowest is in Conghua District at 0.23 km/km^2. The spatial distribution of the Guangzhou greenway varies significantly. It is limited by the actual urban conditions and municipal road conditions. Some urban greenways and community greenways are not continuous, and there are breakpoints within and between greenways, preventing the network from being complete.

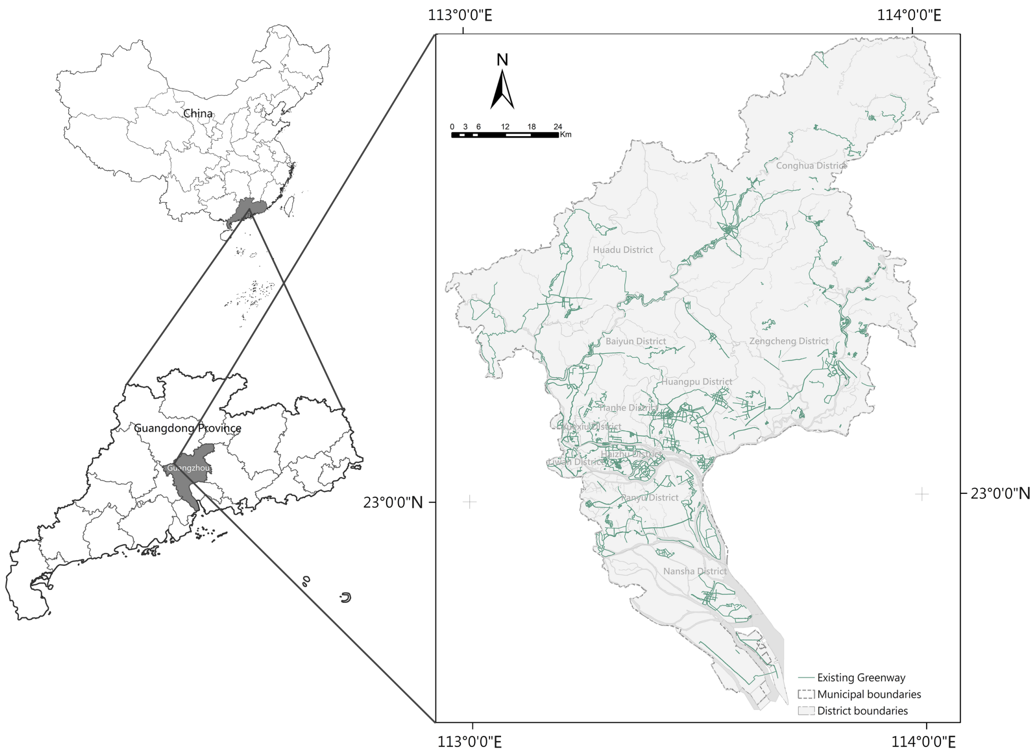

Figure 1. Distribution of greenwys in Guangzhou

Data sources

Multiple data sources, including UGS Big Data and spatial data, were used as the basis for this study. These data were obtained from various sources, as shown in table 1.

Table 1. Spatial data used in the study

Data name	Description	Source	Resolution	Year
Motion trajectories	The trajectory of cycling and walking in	http://www.foooooot.com/	N/A	2017-2021

	Guangzhou			
Greenway	Distribution of greenways in Guangzhou	Provided by GZPI	N/A	2021
Road	Distribution of roads in Guangzhou	Open Street Maps https://www.openstreetmap.org	N/A	2021
GDP	Distribution of gross domestic product in Guangzhou	Spatially distributed kilometre grid dataset of China's GDP https://www.resdc.cn/	1000*1000m	2016
Population	Distribution of inhabitants in Guang	Spatially distributed kilometre grid dataset of China's population https://www.resdc.cn/	1000*1000m	2016
Residential point	Distribution of administrative settlements in Guangzhou	https://www.resdc.cn/	N/A	2020
Scenic Spots	Distribution of scenic spots in Guangzhou, including natural resources and cultural resource	http://www.gz.gov.cn/gzgov/index.html	N/A	2021
POI	Distribution of points of interest in Guangzhou	http://www.bigemap.com/	N/A	2020

Methodology

The following methodologies were used to study the use patterns and the influence mechanisms of the existing Guangzhou greenway: (1) Using Python to obtain data on residents' movement trajectories; (2) Using the use intensity model to recognise the use patterns and identify the potential greenway sections with high usage intensity; (3) Selecting factors which influence the use pattern of greenways and detecting the explanatory power of each factor by geographical detector model; (4) Finally, based on the potential greenway sections and the explanatory power of different influencing factors, determining the weights of the indicators in the greenway suitability assessment system and mapping the distribution of potential greenway in Guangzhou.

Access to greenway movement trajectories

Greenway use pattern may be examined using outdoor movement trajectory data since it captures the residents' spatiotemporal dispersion state and can partially characterise their dynamic use of space. This study develops a Python web crawler to collect data from the website Foooooot (http://www.foooooot.com/), one of the largest outdoor sports recording platforms in China. The program eventually managed walking and cycling data in Guangzhou from 2017 to 2021. Due to the enormous amount of walking data available, this study focused exclusively on the most recent year of walking data. The final results included 3,187 walking data points, 87,721 walking photo points, 1,166 cycling data points, and 20,397 cycling photo points. The GIS platform was utilised within the Guangzhou municipal region to correlate coordinates and filter out 3,160 valid walking data points, 83,103 valid walking photo points, 1,127 valid cycling data points, and 19,058 valid photo points. The last stage is to locate activity tracks throughout the greenway space. The PRD greenway design specifies that the greenway is at least 20 metres wide in the city, considering that spatial errors may occur, ranging from 50 to 100 metres in densely populated areas or cloudy scenarios (Liu et al. 2012). As a result, the greenway's spatial extent was defined in this study as a buffer zone of 50m on both sides of the greenway route, and then the trajectory data was overlaid for filtering. Finally, we obtained 1,301 walking data points, 19,478 photo points of walking, 672 cycling data points, and 5,902 cycling photo points.

Analysis of greenway use intensity

The greenway use intensity is measured by the intensity indicator (U_j), which is calculated based on the number of trajectory points per unit section, characterising the activity power in each section of the greenway. The calculation formula is as follows:

(1) $$U_j = \frac{300 \times \sum_{i=1}^{n} u_{ij}}{L_j}$$

The study selected a 300m road section as a subset of road sections, and the set of road sections was P. The number of tracks meeting the criteria on the Road $j \in P$ is n. U_j is the activity intensity of Road j, u_{ij} is the number of track points of the Track i in Road j, and L_j denotes the length of Road j which is taken as 300m, and those less than 300m are calculated according to the actual distance. The assessment rating is based on the classification of “standard deviation”, which shows the difference between the attribute value and the average value of the element: 0 is “none”, < -0.5 Std. Dev. is “low” use intensity, -0.5-0.5 Std. Dev. is “medium” use intensity, 0.5-1.5 Std. Dev. is “medium-high” use intensity, and > 1.5 Std. Dev. is “high” use intensity.

By spatially superimposing a vast amount of trajectory data, it is possible to limit the influence of individual preferences on the assessment results, thereby displaying an overall spatial and temporal characteristic. Furthermore, the use of the Guangzhou greenway may be objectively assessed by applying precise statistical analysis to each subset of greenway sections.

Mechanisms influencing greenway use intensity

In this study, the geographical detector model was applied to analyse the spatial variance of greenway use intensity based on the hypothesis that the intensity of greenway use and its potential influencing factors are similar in spatial distribution. Four detectors (sub-models) comprise the geographical detector model: factor detector, interaction detector, risk detector, and ecological detector. The factor detector is applied to detect the explanatory power of each potential factor (X) on the use intensity of greenway (Y), where the explanatory power is expressed in terms of q value:

(2) $$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N\sigma^2} = 1 - \frac{SSW}{SST}$$

In this equation, N refers that a study area consists of N units, which is stratified into h = 1, 2, …, L stratum; and stratum h consists of Nh units; $\sigma^2$and σ_h^2 denote the global variance of the dependent variable of the study area and the variance of the dependent variable in the sub-areas; SSW and SST indicate within the sum of squares and the total sum of squares, respectively. The range of values of q is [0,1], with larger values of q indicating a more substantial explanatory power of the independent variable on the use intensity of greenway.

Greenway use patterns result from numerous factors (Liu et al. 2018). Based on previous research on the impact of the built environment on the use of greenways, and taking into account the functions and characteristics of greenways, slight modification to the existing 5D metric system was made to remove the Design factor, a smaller-scale place design element, and because users often refer to scenic and natural areas as important greenway features (Senes et al. 2017), the Distance to Transit was changed to Distance to Scenery. We consider the availability of data and the requirement to quantify indicators, and six variables were selected to estimate the use intensity of greenways, including Population Density, GDP, Land Use Mix, Accessibility, Scenic Spots and Water Bodies. Each factor is calculated as follows:

Table 2. Calculation of impact factors

Modified 5Ds	**Factor**	**Description**	**Method/Formula**	**Source**
Density				
	Population Density	The number of people per square kilometre within the municipal boundaries of Guangzhou	N/A	N/A
	GDP	It refers to the value of GDP per square kilometre within the city of Guangzhou	N/A	N/A

Diversity	**Land Use Mix**	It refers to the relative proximity of different functional sites within a region. Entropy is often used to measure the degree of disorder inherent in a system and can be used to characterise the disorder of urban land uses within a regional parcel.	$ENT = -\frac{\sum_{i=1}^{k} P_i \ln(P_i)}{\ln(k)}$ P_i is the number of each POI type as a percentage of the number of POIs, and k is the total number of POI types. The entropy index takes values ranging from 0 to 1. The higher the entropy index, the higher the land use mix.	Song, Merlin and Rodriguez, 2013
Destination Accessibility	**Accessibility**	It refers to the magnitude of the opportunities for interaction between the nodes in the transport network. This study evaluates the ease of reaching the greenway.	Service area analysis, via the Network Analyst module in ArcGIS, sets a pedestrian walking speed of 4 km/h.	Yenisetty and Bahadure 2021
Distance to Scenery	**Scenic Spots**	This study evaluates the ease of reaching the greenway.	N/A	N/A
	Water Bodies	It refers to the distribution of water bodies in Guangzhou.	Buffer analysis via the Euclidean distance tool in ArcGIS.	N/A

5. Results

Counting the distribution of tracks inside and outside the greenway space, a total of 1,973 trajectories have visited the greenway space, accounting for 46% of the city's sports trajectories, with walking trajectories accounting for 41% of total walking and cycling trajectories accounting for approximately 60% of total cycling. 25,380 photo points were inside the greenway, accounting for 25 % of the total number of photo points. The average walking time and cycling time of citizens using greenway were 2.96h and 4.09h, respectively, higher than the 2.88h and 3.67h, respectively, in Guangzhou. It suggests that outdoor sports enthusiasts, especially cyclists in Guangzhou, favour greenways.

Time characteristics of greenway use

The temporal distribution of greenway trajectories shows that the inter-month fluctuations in overall greenway use (Figure 2a) are highly variable, with a peak of 241 and a trough of 92. The peak of use in March and the second and third peaks in September (212) and November (229), respectively, and the trough in June. The number of walking trajectories and the number of cycling trajectories have similar fluctuating trends. However, the number and magnitude of cycling trajectories are far smaller than walking trajectories. The number of cycling trajectories peaked in November (93), later than the walking trajectories. The inter-month variation suggests that climatic factors strongly influence Guangzhou's greenway use patterns, which is more evident in walking use. The public prefers to use the greenway during seasons of high human comfort (e.g. spring and autumn) and less frequently during the hot and humid summer months, which indicates that climate has a more significant impact on urban outdoor open spaces in subtropical regions.

The intra-weekly variation in the number of greenway trajectories (Figure 2b) demonstrates that weekday and weekend use of greenways varies dramatically. On weekdays, the single-day variance is negligible. However, the number of trajectories is low on Mondays and Fridays, at 183 and 213, respectively, indicating a more downward inclination to use the greenway at the start and end of the week. Weekends had a much higher number of trajectories than weekdays. Even the number of single-day weekend trajectories for all of these rides was 50% greater than the weekday total, showing a high enthusiasm for weekend rides.

In terms of daily use of the greenway, since the time of each trajectory point along the route cannot be collected, a significant number of photo spots marked with precise time are used to evaluate how the greenway's usage changes during the day. As illustrated in the figure (Figure 2c), intra-day fluctuations in use on working and rest days are similar. The greenway is predominantly used daytime, with peaks in the morning (10:00-11:00) and afternoon (15:00-16:00) and a trough in daytime use at midday (12:00-14:00). Nighttime use is significantly lower than during the day, attributed to insufficient greenway lighting or low-quality scenery. Additionally, the data shows that weekends have a somewhat later peak on the time axis than weekdays on average. Their evening activity time is significantly longer, indicating that the public is more inclined to engage in outdoor activities on weekends evenings.

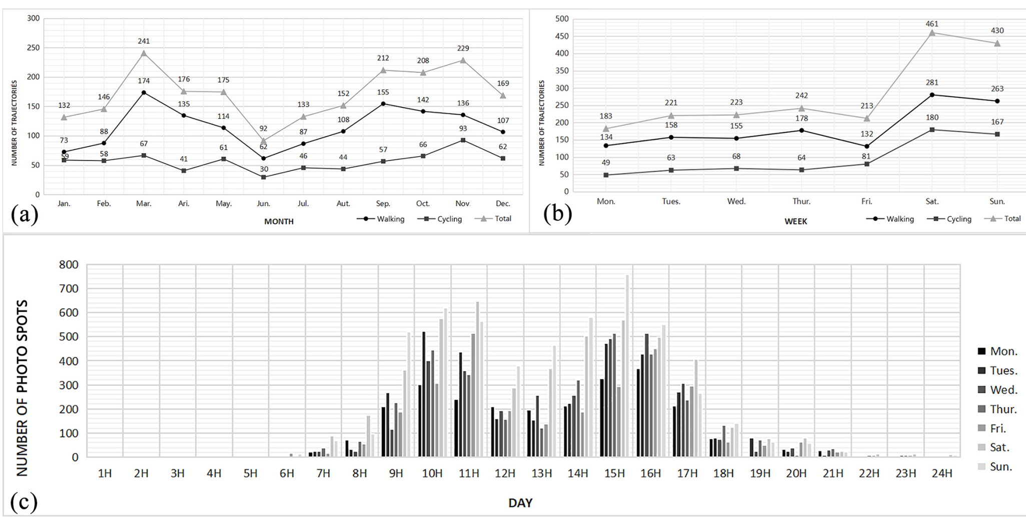

Figure 2. (a)Intra-year variation of the number of trajectories (b) Intra-week variation of the number of trajectories (c) Intra-day variation of the number of photo spots

Spatial characteristics of greenway use

According to the analysis of greenway use intensity (Figure 3a), 73.9% of Guangzhou's greenways have recorded exercise activities, and general use of Guangzhou's greenways was high. The greenway parts with medium-high and high ($U_j \geqslant 0.5$ Std. Dev.) intensity of use is concentrated in the four central municipal districts (Yuexiu District, Liwan District, Haizhu District, and Tianhe District), where the population density is large, and the economy is more developed. Furthermore, public preference is given to greenway parts in central municipal districts that are near the Pearl River and have more excellent landscape resources, such as the Lin Jiang Xi Avenue in Yuexiu District, the Changdi Avenue in Liwan District, and the Bin Jiang Xi Avenue in Haizhu District and the Lin Jiang Avenue section in Tianhe District. In other districts, there are also some sections of medium-high intensity greenway near government sites, such as the central area of Conghua District, or with excellent natural scenery or cultural resources, such as the section in Huadu District's Furongzhang Mountain scenic spot and the section on both sides of the Zengjiang River in Zengcheng District. There are 42.3% of greenway sections with a medium (-0.5 Std. Dev. $\leqslant U_j <$ 0.5 Std. Dev.) intensity of use, primarily near attractions or large parks, such as the section around Haiou Island in Nansha District and the section in University City in Panyu District; and 22.0% of greenway sections with a low ($U_j <$ -0.5 Std. Dev.) intensity of use, mainly connecting central urban areas or attractions. Moreover, 26.1% of greenway sections lacked utilisation data; for instance, some of the more remote greenway sections from the district centre even had no usage data for large sections, such as the section between Chini Town and Tanbu Town in Huadu District.

Additionally, there are considerable disparities in the district-by-district distribution of greenway use intensity. The total intensity of greenway use in central municipal districts is typically above medium and evenly distributed. In contrast, the intensity of greenway use is relatively low and unevenly distributed throughout the remaining municipal districts. There are sections of greenways with high intensity of use and other sections where the intensity of use is too low, and almost no data is available. For example, due to the long route and the low population density of the surrounding area, the limited crowd activity in the Conghua Greenway is mainly concentrated in the scenic section of Fengyunling Mountain, Liu Xi Lake - Wuzhishan Mountain, and other sections of the greenways with high accessibility near the city centre, while the remaining sections have little to no crowd activity due to their lack of attraction.

When comparing the intensity of walking and cycling on the greenways, it was discovered that cycling intensity was more evenly and centrally distributed in the geographic space (Figure 3b and 3c), consistent with the cycling's long-distance and time spent features. However, the proportion of medium-high and high use of greenway cycling is lower than that of walking, with only 4.0% sections of cycling of medium-high and high intensity, compared to 8.1% of walking sections, and the location distribution is almost identical to the overall intensity of use on the greenway. It implies that the greenway environment is less appealing to cyclists, leading to a lower rate of route repetition for cycling. At the same time, for pedestrians, some sections are shorter, closer to residential areas, and rich in landscape resources can be repeated, thereby making the Guangzhou Greenway a better pedestrian environment than a cycling environment in relative terms. There is also a tremendous difference in cycling and walking intensity within a section, for example, in the Panyu District's Haiou Island section and the Shiqiao Waterway section of the greenway, where cycling intensity is higher than walking intensity due to the route's length and limited accessibility to residents on foot.

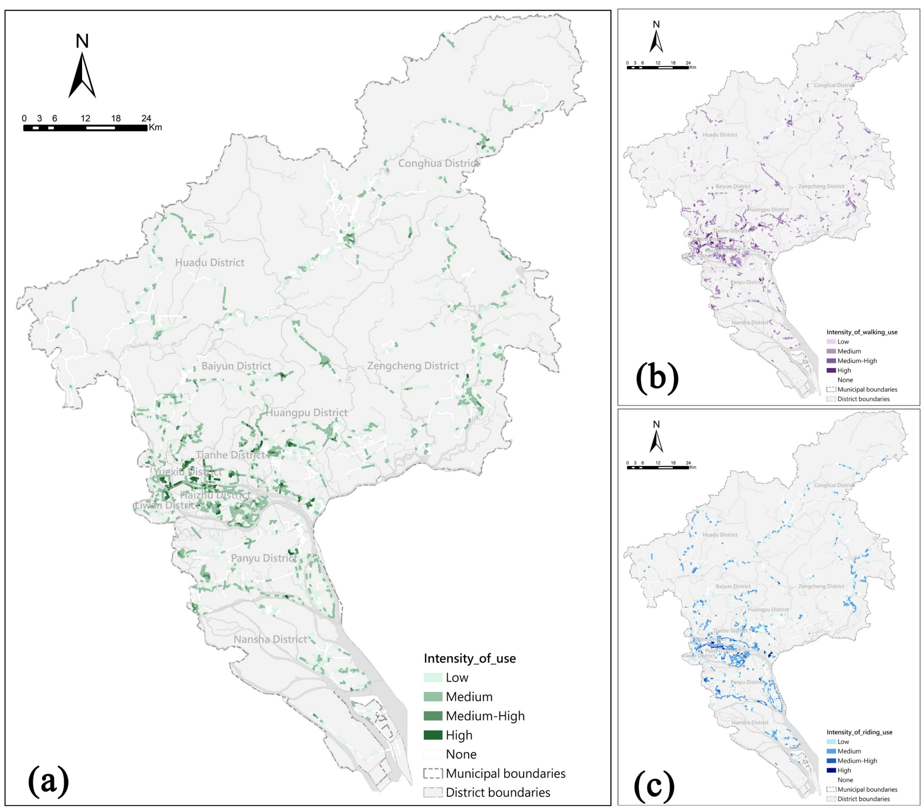

Figure 3. (a) Use intensity of greenways (b) Walking use intensity of greenways (c) Riding use intensity of greenways

Influence mechanism of greenway use

By utilising the geographical detector model, we can identify the influence of each factor on the intensity of greenway use. The results (Table 3) show that the explanatory power of each factor is, in descending order, GDP > Population Density > Water Bodies > Scenic Spots > Accessibility > Land Use Mix. At the municipal scale, the intensity of greenway use is mainly influenced by GDP and Population Density, as residents of economically developed and densely populated areas are more inclined to use public space for outdoor activities. In Guangzhou, the most economically developed and highly inhabited areas include Haizhu District, Yuexiu District, Liwan District, and Tianhe District, where the density of greenways exceeds 1 km/km^2, significantly more than the average density of greenways in Guangzhou. When the greenway intensity map (Figures 4a and 4b) is superimposed, it becomes clear that these four municipal districts, which cover only 4% of the municipal area, account for 64% of the city's medium-high and high-intensity greenways. The next most influential factor in the intensity of greenway use is Water Bodies. As shown in Figure 4c, 55% of the greenways are within 100m range of Guangzhou's water bodies, and 69% of the medium-high and high-intensity greenways are located within this area, indicating that waterfront greenways are more popular. The Scenic Spots also have an explanatory power above 0.1; according to Figure 4d, 67% of the greenways with medium-high and high use intensity are located within a 15-minute walk of the scenic spots, implying that greenways situated relatively close to the scenic spots will have a high use intensity. While Accessibility and Mixed land use have less predictive potential for greenway use intensity, there is some spatial resemblance between these two variables and greenway use intensity. And overlaying the greenway use intensity map and greenway accessibility (Figure 4e) reveals that 80% of greenway sections with medium-high and high use intensity are located within 15min of residents' walking range. Over 42% of the low use intensity and no data greenway sections required residents to walk at least 15 min. Overlaying the Land Use Mix map (Figure 4f) shows that the high land mix in Guangzhou is mainly located in Yuexiu District, Tianhe District, Liwan District, Haizhu District, Panyu District, and the central urban areas of other municipal districts. The variety of uses in these locations enables residents to travel fewer distances between their points of departure and destinations. As a result, inhabitants of these areas prefer healthier modes of transportation such as walking and cycling, making greenways popular.

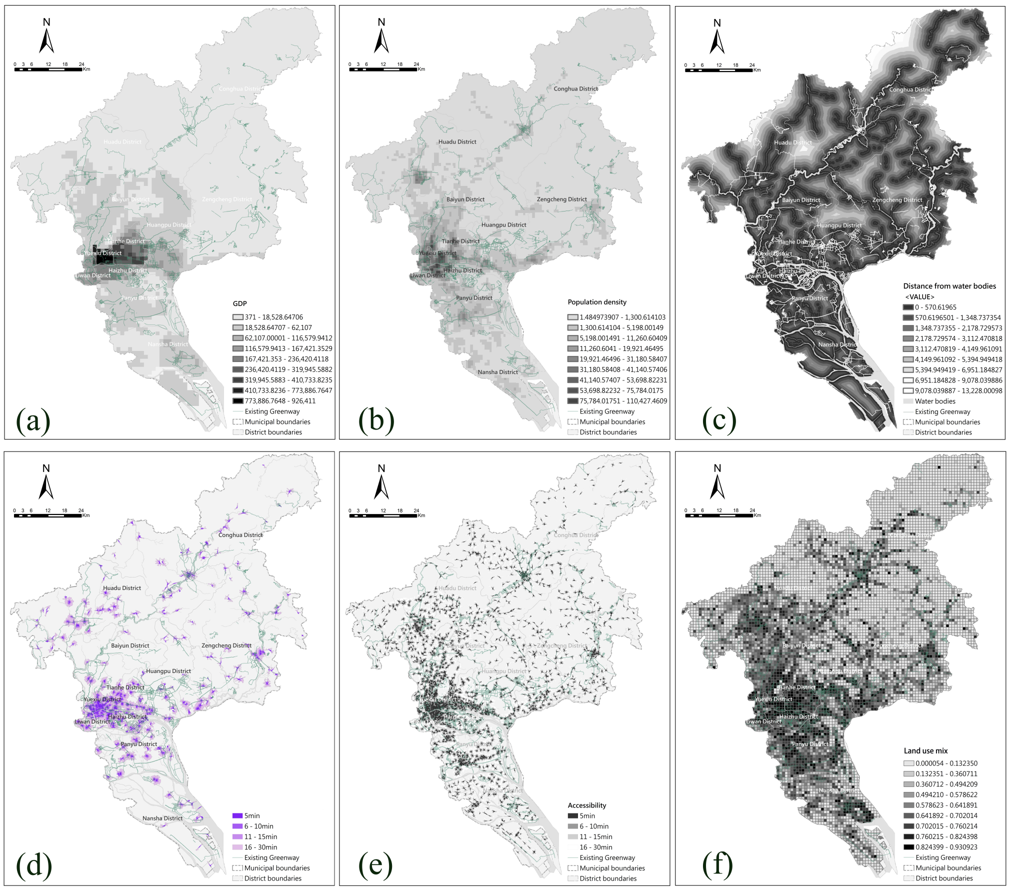

Figure 4. (a) Spatial distribution of GDP (b) Spatial distribution of Population Density (c) Distance from Water Bodies (d) Spatial distribution of Scenic Spots (e) Accessibility of the Greenway (f) Spatial distribution of Land Use Mix

Table 3. The factor detector results of greenway use intensity

Factor	GDP	Population Density	Land Use Mix	Accessibility	Scenic Spots	Water Bodies
q statistic	0.280	0.205	0.074	0.076	0.143	0.176
p value	0.000	0.000	0.000	0.000	0.000	0.000

Construction of greenway suitability assessment system

While studying the greenway use intensity, it was discovered that many sections are not planned as greenways but are heavily used. These linear spaces, which are densely populated, connect the current greenway network and have significant potential to complement it. Thus, by layering municipal movement trajectories and the municipal road network, this study obtained a map of Guangzhou's municipal road use intensity distribution (Figure 5a) and selected roads with medium-high and high use intensity as alternative greenway sections. Based on the geographical detector model, it was found that the explanatory power of each factor on the greenway use intensity was GDP > Population Density > Water body > Scenic Spots > Accessibility > Land Use Mix. By using it as the basis for assigning scores, the weights of the influencing elements were determined using the Analysis of Hierarchy (AHP) approach (Table 4), and a map showing the greenway's suitability was created (Figure 5b). Finally, the satellite data was used to evaluate whether road sections met the criteria for conversion into greenways, resulting in a map of potential greenways in Guangzhou (Figure 5c). According to the suitability classification, the potential greenways are divided into two categories: important and secondary important, with the important potential greenways totalling 66.6 km in length, mainly located in the four central municipal districts of Guangzhou, to complement and improve the existing greenway network, further increase the connectivity of the greenway network and reduce the travel costs for residents to access the greenways. The secondary important potential greenways are 196.1 km in length. They are mainly located in the suburban areas of Guangzhou, including Huangpu District, Zengcheng District, Conghua District, and Panyu District, with the main function of linking up more dispersed landscape resources and enhancing the attractiveness of the greenways and attractions.

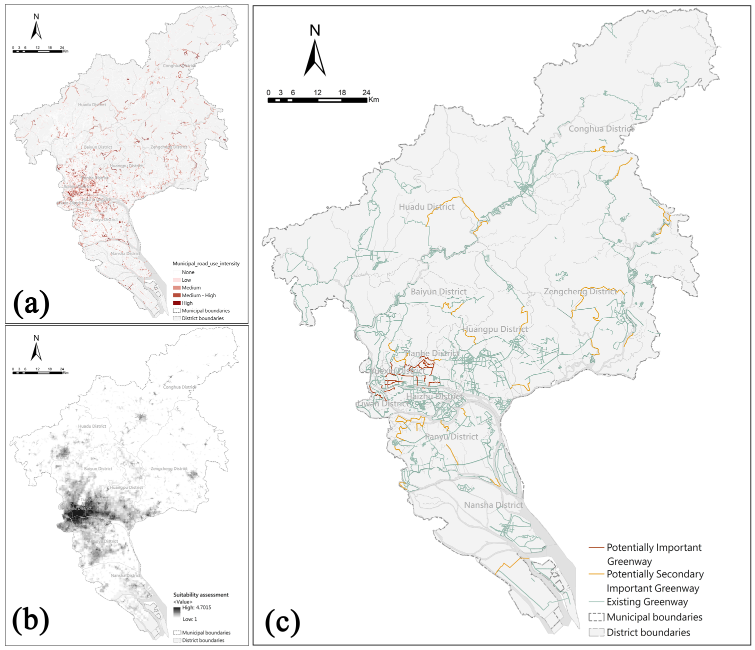

Figure 5 (a) Use intensity of road network (b) Greenway suitability assessment (c) Potential greenway distribution

Table 4. Results of AHP

Factor	Feature vector	Weights	Maximum characteristic root	CI value
GDP	1.9524	0.2907	6	0
Population Density	1.4464	0.2154		
Land Use Mix	0.523	0.0779		
Accessibility	0.5381	0.0801		
Scenic Spot	1.0112	0.1506		
Water Bodies	1.2444	0.1853		

6. Discussion and Conclusion

This study conducted a preliminary investigation of greenway use patterns in Guangzhou through UGC Big Data, evaluated the explanatory power of built environment factors on the intensity of greenway use with the geographical detector, and then developed an assessment system for suitability greenways in Guangzhou. It leads to the following conclusions:

1. Actual user demand and planning policy may not always correspond perfectly. More than half of Guangzhou's walking and cycling activities occur outside the greenway, while nearly half of the greenway's sections lack user exercise data or are used at a low intensity, indicating that the greenway's top-down planning based on the land policy does not fully meet the public's need for outdoor activities.

2. Among districts, the utilization of greenways is different and unevenly distributed. The old urban areas, led by Yuexiu District, Liwan District, and Haizhu District, are economically developed, densely populated, with a good road network and diverse landscape resources, resulting in a high level of greenway use. In stark contrast, the new urban areas, represented by Conghua District, Huadu District, and Nansha District, are vast and sparsely populated. The greenway is thus underdeveloped, and its construction is slow-paced. Resources, like tourist sites, are also few and far between. The neglectable portions of medium-high and high-intensity greenways are concentrated in these districts' central areas and scenic areas, while greenways connecting them are mainly of low intensity or have no relevant data.

3. Of the influencing factors, GDP has the most significant influence on greenway use patterns, followed by population density, indicating that users in economically developed and densely inhabited areas will use greenways more intensively. Additionally, the distribution of water bodies and scenic spots has a relatively high effect, reflecting a greater general preference for greenways close to water bodies and resource sites with panoramic views. However, due to the random nature of population activity and the limited sample size within the greenways, the influencing factors' explanatory power on the intensity of greenway use in this study is restricted.

Greenways are still under construction in various countries. This study may provide some references for improving and upgrading existing greenways and the selection of additional routes for future greenway networks.

Upgrading and optimisation of existing greenways

Through the evaluation of greenway use patterns, the study screens out greenway sections in the existing greenway network that lack data and have a low intensity of use and then analyses relevant influencing factors to determine whether the greenway is affected by one or a combination of factors such as geographic location, socioeconomic status, natural environment, or cultural benefits. Based on this, a follow-up field research will be conducted, and suitable adaptation actions will be done. For example, greenways on the periphery of the city that are close to ecological protection sources and receive little or no use can be converted to ecological greenways that are conducive to biodiversity; greenways in areas with development potential can be enhanced by enhancing the landscape quality, service management quality, and spatial accessibility both inside and outside the greenway, thereby increasing livability and attractiveness and fostering a positive virtuous circle. For sections with a high level of usage, attention also needs to be paid to assessing the carrying capacity of the space and implementing particular interventions that use additional high-quality paths to divert traffic and strengthen the spatial use's resilience fairly.

Complement and construction of potential greenways

Due to budgetary and time constraints, future greenway design and alignment selection must prioritise and focus on specific sections of the greenway to make the most use of available resources. This study considers the public's actual needs by screening out linear spaces with a high level of use; secondly, priority should be given to building greenways in densely populated areas with a high demand for public space, as well as increasing the accessibility of greenways to settlements to serve more neighbourhood residents; thirdly, parcels with a higher mix of land should be considered for connection to the greenway, as these parcels provide users with a closer destination to their starting place and encourage the use of slow-moving modes of mobility. Finally, greenways should connect more landscape resource sites, with a preference for waterfront greenways adjacent to waterways, giving users more diverse options and increasing the efficiency of the greenway's use and the site's appeal.

Research limitations and prospects

This study aims to supplement the existing system of greenway evaluation with a more quantitative and objective method. First, the inclusion of user-generated content (UGC) data provides a more intuitive image of the spatial and temporal distribution of people's activities, hence expanding the scope of greenway evaluation. Second, the use of the geographical detector enables quantification of the spatial similarity between the intensity of greenway use and its influencing factors. On this basis, ranking the degree of influence of each element can provide a more objective criterion for assigning a score to the suitability evaluation system. However, this paper's research methodology has certain shortcomings. Because the UGC data is dependent on users' use of a certain platform, its representational ability is limited. The network's user base is predominantly young and middle-aged. It is frequently challenging to collect information and photographs of older adults' activities due to their rustiness in using the online platform. Simultaneously, while the study gathered photo distribution locations, it did not conduct additional analysis of the photo content, leaving the psychological views of greenway users' subjective psychological sentiments undeveloped.

Although the optimised urban greenway network in Guangzhou is scientific in nature, there may be some discrepancies between the primary data and the actual situation, which means that additional field research and machine learning will be required to implement it down to the street level and provide specific guidance and transformation suggestions for each greenway. Meanwhile, we will continue to collect more comprehensive drivers to improve and enrich the evaluation system. We will research the universal construction process to apply it to other cities and regions in the greenway selection process.

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