THE ASSOCIATION BETWEEN GREENNESS, HEALTH, AND WELL-BEING IN URBAN ENVIRONMENTS

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THE ASSOCIATION BETWEEN GREENNESS, HEALTH, AND WELL-BEING IN URBAN ENVIRONMENTS

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Table of Contents

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EDITORIAL
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Editorial: The Association Between Greenness, Health, and Well-Being in Urban Environments

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Keywords: greenness, health and well-being, urban environments, green space, urbanization

Editorial on the Research Topic

The Association Between Greenness, Health, and Well-Being in Urban Environments

The collected articles address a wide range of critical issues, such as accessibility, environmental satisfaction, air pollution, social-cultural values, and ecosystems, which link urban greenness and urban residents' health and well-being in multifaceted perspectives.

Several articles in this special issue focus on how older people's mental health and well-being are affected by green space. Zhou et al. contributed an important study to this special topic by clarifying the link between green space and older people's mental health and well-being. They used multi-scale data including both remote sensing and questionnaire surveys. Their study argued that there is a critical element linking green space and mental health, that is social interaction. Therefore, planning and designing green space for social interaction should be included in the study of green space and health. This special topic also includes a study looking at the older people from diverse cultural backgrounds. Gao et al. investigated older Chinese immigrants in Australia and found out their green space preferences. The physical activity and good accessibility to green space have been valued by Chinese immigrants, which has important implications for designing inclusive public space. Zhai et al. contributed another empirical study about the link between older people's walk behaviors and park features. Their study identified a series of park characteristics that can be used to create walkable parks and outdoor spaces. Shi expanded the enquiry of green space beyond the psychological well-being; she argued that green space also means environmental comfort, hygiene and security to the senior citizens in Hong Kong. Based on her studies in public housing in Hong Kong, she identified some critical design elements to enhance older people's perception of security, hygiene, and environmental comfort in public green space.

Promoting equitable access to green spaces is crucial to the construction of sustainable and equitable cities. He et al. examined the extent to which different types of green spaces (urban parks and other urban vegetation) were provided to the total population (referring to as horizontal equity) and different social groups (referring to as vertical equity) in an equitable manner in Wuhan, China. Their findings suggested that the inequity of public parks was more intense than mixed and woody vegetation, and that urban green space supply was highly skewed toward the inner and outer areas. Cheng et al. took a dynamic community deprivation consideration and looked at the accessibility issue from the perspective of transport modes and traffic networks. Their results highlighted the socioeconomic factors underlying the disparity of accessing to the urban green space and called for political attention to the inequality of green space accessibility.

This special topic also collected articles focusing on the physical health benefits of greenness, such as reducing risks of air pollution, skin disease and obesity. Using air quality monitoring

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data from 285 cities in China, Wang et al. explored the effect of green coverage (GC) on PM2.5 concentration during peak hours. They found a considerable heterogeneity across cities regarding the marginal effect of GC on the mitigation of PM2.5 concentration. They also indicated that government expenditure on urban maintenance could mitigate air pollution through economic development. For this reason, policymakers from different regions were advised to use different combinations of policies to mitigate air pollution. Acne vulgaris is a commonly seen skin disease that has a considerable impact on the quality of life. Yet the complex association between environmental factors and the occurrence of acne is unknown. Yang et al. provided a comprehensive review of literature on the impacts of individual and contextual factors on the occurrence of acne. They further indicated the possible pathways linking built environment to the pathogenesis of acne and called for more empirical studies to test their suggested pathways. Xiao et al. used a deep convolutional neural network architecture to extract eye-level information from Street View images to capture the urban vertical greenness level and identified the view-based green index that might have an protective effect on body weight.

The perception and satisfaction of green space has been investigated for different groups of users. He et al. explored cyclists' perception and experience of using greenway in Wuhan. The research addressed the cyclists' landscape imagery and their visual perception elements that should be well-understood in designing greenways. They found four features that contribute to a positive cycling experience: continuous cycling paths, high security awareness, open landscapes, and rich human activities. Chen et al. took a disparity perspective to study the perceptions of urban green space between residents and tourists nearby East Lake in Wuhan and identified the underlying difference of perceptions between the two groups. Qiao et al. used an individual survey from Shenzhen metropolitan areas to document the mediating role of satisfaction on the relationship between green space and urban residents' mental health. Mao et al. defined cultural ecosystem services in a broad sense that include green space to enhance mental health, social belonging, group identity, and social integration. They surveyed 40 communities and their residents in Zhengzhou, China to demonstrate the compensation effect of green space in response to the lack of nearby parks. They also addressed the important role of natural vegetation in urban residential communities' cultural ecosystem services.

This special topic has attracted contributions on a broad spectrum of dimensions of the green space availability issue. The topic has inspired a dialogue between different disciplines that is crucial to understand the complex relationship between availability of green spaces and public health. The sample size is becoming larger and more extensive, to capture the complex urban environments and populations. The link between greenness and health and well-being remains inconclusive, awaiting new methodologies, techniques and measurements. Another limitation is that all contributions are from studies conducted in China except one, in Australia on Chinese immigrants. An obvious question is whether findings from such studies could be applied to other settings such as Europe or the U.S. It might not be necessarily the case. However, the studies covered in this special topic show promising evidence to support that urban greenness promotes the health and well-being of various population subgroups in various contexts.

Last but not least, the editorial team would like to thank every author and reviewer for their contribution to this special topic.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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The editorial team would like to thank every author and reviewer for their contribution to this special topic.

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Characterizing Horizontal and Vertical Perspectives of Spatial Equity for Various Urban Green Spaces: A Case Study of Wuhan, China

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Equity has been a major concern of urban green space provision. Whether the urban green spaces are equitably provided for socially disadvantaged groups is an important issue in the field of social and environmental justice. This topic is particularly significant in fast-growing Asian countries like China experiencing widening income disparity. This paper examines whether and to what extent the different green spaces (including public parks and urban vegetation) are equitable for all populations (referring to horizontal equity) and also for different social groups (referring to vertical equity) in this typical inland city—Wuhan, China. A novel indicator combining proximity and quality is presented to assess the supply of public parks. The Theil index provides a decomposable measure of overall equity across different regions and vulnerable groups. Both horizontal and vertical perspectives are compared to characterize the spatial equity of urban green spaces (including public parks and urban vegetation) across all population and across different social groups. The empirical analysis of the inland city showed that the overall supply of public parks is far more unequal than mixed or woody vegetation. The distribution of public parks is more inequitable in the outer area, whereas the distribution of mixed or woody vegetation is more inequitable in the inner area. Furthermore, the geographic detector analysis is employed to investigate the spatial relation between socioeconomic contexts and urban green spaces. The spatial heterogeneity of education and age groups is statistically significant for explaining the distribution of public parks. Meanwhile, population density clearly plays a role in the distribution of both public parks and urban vegetation. Per capita income can explain 26% of the distribution of public parks but is not significantly associated with mixed or woody vegetation. Finally, the vertical equity of urban green space is also examined in this paper that the vulnerable groups in the inner area, such as females, residents with low education, children, and the elder suffer from highly unequal accessibility to parks, whereas the vulnerable group in the outer area, such as the migrants gets unequal access to parks.

Keywords: spatial equity, Theil index, green spaces, environmental justice, China

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INTRODUCTION

As providers of regulating and cultural ecosystem services, the significance of green spaces has been widely acknowledged, such as purifying the air, reducing traffic noise pollution, increasing carbon storage capacity, reducing urban energy consumption, promoting the physiological and mental health of urban residents, etc. (1, 2). Because of these social, economic, and environmental benefits, there may be competition in societies' interactions with urban green space, leading to the equity issue to determine the fairness of such interactions (3). With increasing urbanization in the globe especially in Asian countries, the issue of population densification in urban areas puts much pressure on maintaining and improving the amount and quality of green space supply (4). Sustainable urban development requires supply and demand mismatches of green space are to be reconciled and the needs of different stakeholders are to be balanced (5).

Horizontal and vertical equity were initially defined for evaluating tax reform (6). The horizontal equity as a minimal rule of fairness requires the equal treatment of all population whereas the vertical equity calls for an appropriate pattern of differentiation (inequality in treatment) among people who are not equals, such as the low-income, children, or ethnic minorities (7). Such a concern raises very difficult problems when comparing groups across different cultures or even different social classes as almost inevitably follows when dealing with vertical equity (8). There is common support for improving horizontal equity while remaining neutral on the controversial issue of vertical equity.

There is a small but growing body of studies in U.S. or Europe exploring the differentiated distribution of green space in relation to age, religion ethnicity, minority status, and education. Taking 10 US urbanized areas as examples, Nesbitt et al. (9) find a strong positive correlation between urban vegetation and higher education and income across most cities, and negative correlations between racial minority status and urban vegetation. Jay and Schraml (10) focus on immigrants and examine the role of urban forests for migrants in terms of their uses, perception, and integrative potential. La Rosa et al. (11) presents a planning framework for urban green spaces that aims to minimize social inequalities in green space accessibility and meet demands from social groups (e.g., children and elderly people).

These studies have started to emphasize the demand of socially disadvantaged groups for green spaces, but issues of equity and justice in the distribution and enjoyment of urban green spaces are still required, especially in the Chinese context. First, China is experiencing widening income disparity and urban gentrification is spreading across the continent (12). High-income people tend to enjoy the benefits of the environmental good. Second, the rural-to-urban migration is a quintessential feature of economic development and modernization in China. Almost 20% of the Chinese population are composed of migrants and their descendants. Influenced by the rigid *hukou* registration system, residents with migrant background are more likely to struggle with unemployment and low income (13). Uncovering the spatial equity of urban green spaces especially for different social groups is the basis to maximize societal benefits for the local government.

The distribution and governance of urban green space are inequitable in many cities around the world (14, 15). Public parks and woody vegetation are more often located in wealthy neighborhoods, where residents have higher education and income (16, 17). There is evidence that socioeconomically disadvantaged and racialized minorities have lower access to urban green space and are less likely to engage in urban forestry decision making (11, 15). It is important that residents have equitable opportunities to reach urban green space because of the ecosystem services that influence the well-being of residents, especially among the people who have lower political, social, and economic power.

Presently, the studies about social and environmental justice are mainly based on empirical studies of individual cities or regions in North America or Europe. There is evidence that variable results are produced among different geographical areas, different cultures, and urban areas with different development histories (10). The empirical study on the equity issue of urban green space in Chinese cities may consolidate the related theoretical framework in the field of environmental justice or political ecology and provide comparative results to the existing studies (18–20). It needs to be further explored how the equity of various urban green spaces differs across all population and across different social groups, and how the equity issue is associated with the spatiality of urban space.

This paper aims to provide horizontal and vertical perspectives for analyzing spatial equity of green space with a case study of Wuhan, using techniques, such as Theil index and geographic detector analysis. Then, the study area and methodology are described. Based on the overall horizontal inequality of green space supply, we decomposed the horizontal green space inequality according to the spatial structure into inequalities among the inner, middle, and outer areas. Furthermore, we mapped the horizontal equity gaps and observed the sweet spot and the sour spot of urban green spaces. Based on geographic detector analysis, the spatial relation between socioeconomic contexts and urban green spaces is investigated. The vertical equity is discussed as well to assess how the equity of various urban green spaces differs across different social groups. Finally, this paper ends with major conclusions and policy implications.

DATA DESCRIPTION AND METHODOLOGY

Data Description

The Study Area

Wuhan, with a longitude of 11341'11505′ and a latitude of 2958′3122′, is situated in the eastern part of Hubei in central China. By the end of 2017, Wuhan has a land area of 8,569.15 km^2 with an urbanized area of 628 km^2. The city is divided by the Yangtze River and Han River into three towns: the commercial town of Hankou, the industrial town of Hanyang, and the educational and high-tech town of Wuchang. The city's three ring

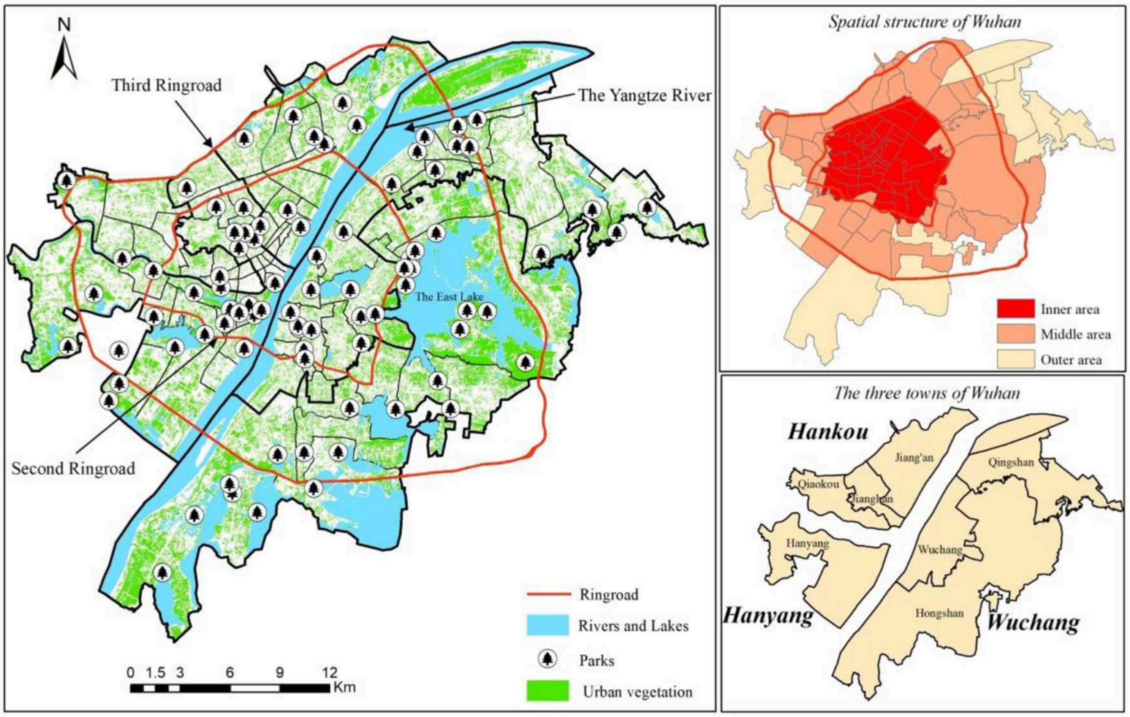

FIGURE 1 | The study area of Wuhan.

roads demarcate three concentric areas of development: the inner area, the middle area, and the outer area.

In 2017, the total investment for city greening reaches 9.20 billion RMB and 659.35 hectares of green space areas were newly built this year. At the end of 2017, the areas of green space amounts to 20,947 hectares in the urbanized area of Wuhan and the coverage ratio of green spaces reaches 33.35%.

This paper chooses the largest inland city—Wuhan—as the study area for the following reasons. First, previous studies mainly focused on developed countries in North America or Europe. There are only a few empirical studies focusing on the issue of environmental justice in developing countries like China, but many of them paid much attention to coastal metropolitan cities like Beijing, Shanghai, and Shenzhen (21–23). The case study of inland cities helps to enrich the existing empirical findings (24). Second, Wuhan is undergoing rapid economic growth with a nominal growth rate of GDP in 2018 arriving at 10.72%. As the household income increases, residents in Wuhan raise new estimates of the demand for green space to enhance their quality of life. An assessment of whether the distribution of green space provides equitable opportunity for all residents, especially for disadvantaged social groups, such as low-income people, migrants, and children, is crucial for determining where such demands are best met. There are 2.57 million migrants living in Wuhan, accounting for almost 30% of all population. How they get access to urban green spaces and enjoy the environmental good are important for urban planners and policy-makers to improve social justice. Third, Wuhan is partitioned by the ring roads into three regions, namely, the inner, middle, and outer areas. It remains unknown how the spatial circular structure will have an influence on the spatial equity of various green spaces.

The study area is composed of 89 *jiedao-level* sub-districts in seven urban districts of Wuhan as seen in **Figure 1**. The population density of the study area is 6,850 persons per km^2. The inner area as the old commercial center has many old buildings, which puts great pressure on urban renewal. The middle area was developing rapidly after the 1990s and the outer area provides a lot of cheap land for housing and infrastructure construction in the process of urban expansion.

Socioeconomic Variables

Socioeconomic data were obtained from the sixth Chinese population census (the year of 2010) across *jiedao* units. There are three kinds of socioeconomic variables: socioeconomic data, demographic data, and contextual data, and the descriptive statistics of these variables can be seen in **Table 1**. Socioeconomic data include the average level of per capita income in each unit. Demographic data include the number of population in different social groups across a range of gender groups, *hukou* groups, educational groups, and age groups. Gender groups refer to the female and male population. *Hukou* groups included local residents (Local) with *hukou* and migrants without *hukou* (Migrants). The *hukou* registration status warrants the local residents some vital services and welfare entitlements including free or subsidized health care, retirement benefits, and subsidized food and housing (25, 26), whereas migrants cannot

TABLE 1 | Descriptive statistics of socioeconomic variables.

Variables	Mean	Std. dev.	Min	Max
Gender groups				
Female population	35,082	28,908	1,335	169,926
Male population	33,252	25,763	1,019	144,170
***Hukou* status**				
Local population	35,928	31,080	524	197,699
Migrants population	32,406	32,574	364	165,062
Education background				
Edu_low population	27,522	22,778	898	136,996
Edu_high population	16,996	10,430	474	47,587
Edu_uni population	22,125	32,422	159	22,5707
Age groups				
Children population	5,955	4,541	128	20,931
Youth and adult population	56,910	47,497	1,994	277,550
The elder population	5,469	3,629	105	18,580
Socioeconomic data				
Population density	24,581	20,972	206	90,732
Per capita income	2,215	581	481	3,954

enjoy these subsidies and social welfare as an urban citizen. Educational groups included population having middle school or below (Edu_low), high school (Edu_high), and university or above (Edu_uni). Age groups included children (under 15 years old), youths and adults(15-64) and the elder (65+). These characteristics are closely associated with high demand of urban green space (27). The contextual data mainly include population density as a rough proxy for built environment (28).

Methodology

Quantification of Urban Green Spaces

Urban green spaces are measured in two ways: mixed or woody vegetation and public parks. These two categories of urban green space reflect the different ecosystem services that urban residents may receive from different types of urban vegetation. On the one hand, mixed or woody vegetation is more related with reduced flooding, psychological benefits, biodiversity conservation, and higher air quality (9). On the other hand, public parks are more associated with opportunities for recreation and health benefits from urban health.

Previous studies mainly focus on the spatial distribution and the accessibility of various green spaces, producing the use of a “location-” or “accessibility”-based measure for green space provision (4, 29). Following the two-factor theory, distance is found to be the most important precondition for restricting the use of green space (30). Once this precondition is fulfilled, the qualities of green space (e.g., naturalness and facilities) will determine how long the users will stay (31). Thus, apart from investigating the proximity of green space, the quality of green space in relation to residents’ needs will be assessed in this study.

This paper constructs the park supply index combining both the proximity and quality of green spaces, which calculated the service level of walking-distance catchments within a given spatial unit. The park supply covers by this index includes forest parks, city parks and community parks across the central city of Wuhan. The calculation of this index is detailed in Kii and Doi (27), which originated from the field of public transport. The calculation uses the following form:

$$PS_i^* = \sum\nolimits_N \frac{Area_{Bn}}{Area_i} \times PQ_{Bn} \quad (1)$$

$$PS_i = \frac{PS_i^* - \min_i PS_i^*}{\max_i PS_i^* - \min_i PS_i^*} \quad (2)$$

where PS_i is the normalized park supply index for the *jiedaoi* ranging 0–1; PS_i^* is the park supply index for the *jiedaoi* before normalization; N is the number of walk access buffers to parks in each spatial unit; Bn denotes buffer n for each park in each spatial unit; $Area_i$ is the spatial area of the unit i; $Area_{Bn}$ is the spatial area of the buffer n; PQ_{Bn} denotes the park quality for each park buffer n, in the form of a score from 0 (the worst) to 100 (the best).

The standard for evaluating park quality combines two parameters: ecological and social. The ecological parameter includes green space proportion, lake or river, habitat animals, and habitat plants (32), whereas the social parameter includes natural beauty, recreational facilities, park size, no charge, desired visiting frequency.

Figure 2 describes how to calculate this index. First, a spatial database of parks, road networks, and *jiedao*-level administrative divisions was obtained. This includes the location of park entrances, the road network, and the spatial boundary of *jiedao* units. Second, this database was integrated with a database of park quality in the central city of Wuhan. Data were calculated according to the abovementioned equation. Third, access distance to each park was measured for each *jiedao* unit assuming the following threshold of walk access, which is based on typical walk catchments (termed walk buffers) for leisure activities in parks. These are the distance that 75 or 80% of people would walk to access a park for leisure activities within 10 min of walk[1]. Fourth, the spatial analysis tools called network analysis and proximity analysis were employed in ArcGIS 10.2.

The quantity of urban vegetation is recognized to be the direct indicator reflecting the supply of green spaces. If the Normalized Difference Vegetation Index (NDVI) value of the pixel is larger than 0.1, then this pixel is classified as urban vegetation. Therein, NDVI is obtained from the WorldView-2 image with a spatial resolution of 0.60 m. The index of mixed or woody vegetation coverage ratio is calculated in this paper as below:

$$CR_i = \frac{GS_i}{Area_i} \times 100\% \quad (3)$$

where CR_i denotes the coverage ratio of green space in the spatial unit i; GS_i is the total area of green space within the spatial unit i, which could be obtained from the NDVI imagery; $Area_i$ is the total area of the particular unit i.

[1]According to the study of Nesbitt et al. (9), many municipalities in U.S. use a 10-min walk to a park as a park accessibility target.

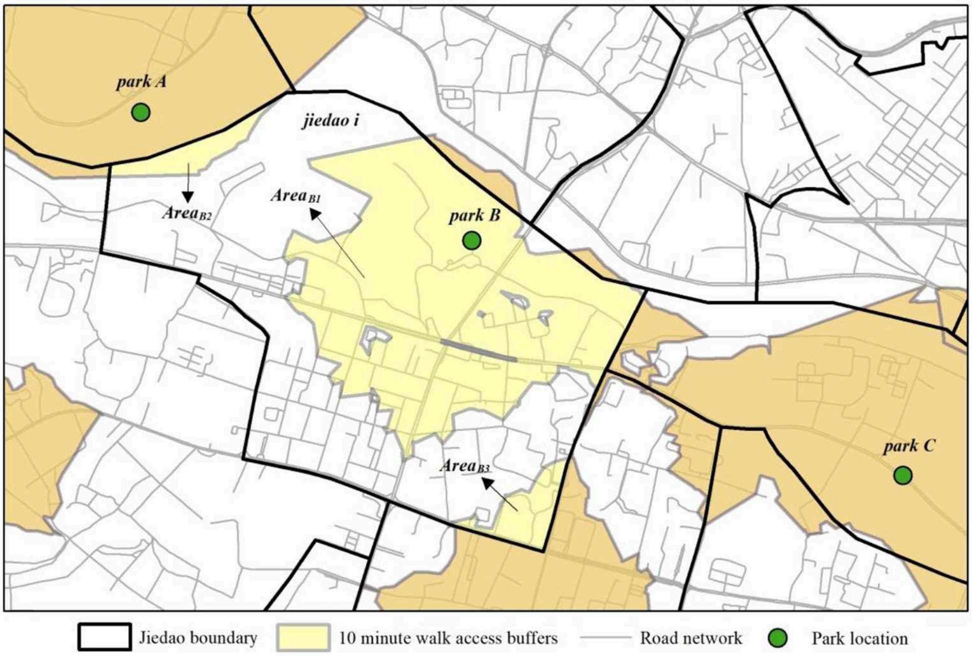

FIGURE 2 | The schematic diagram how to calculate park supply index.

Theil Index for Inequity Measurement

This study deploys the Theil index for measurements of green space inequities. Theil index is applied because of its advantage in decomposability over other indicators like Gini, Atkinson, Standard Deviation, Coefficient of Variation, etc. Theil index is one special case for the Generalized Entropy family when $\alpha = 1$. The calculation of Generalized Entropy and its decomposability will be elaborated as follows. Denote a population of persons, $i = 1, \ldots, n$, with income y_i. Let $f_i = 1/n$ when the data are unweighted. Arithmetic mean income is m. Then, the Generalized Entropy could be formulated by

$$GE(1) = \sum_{i=1}^{n} f_i \times (y_i/m) \times log(y_i/m) \quad (4)$$

Each $GE(1)$ index can be additively decomposed as $GE(1) = GE_w(1) + GE_b(1)$, where $GE_w(1)$ represents within-group inequality and $GE_b(1)$ denotes between-group inequality (33). Suppose there is an exhaustive partition of the population into mutually exclusive subgroups $k = 1, \ldots, K$.

$$GE_w(1) = \sum_{k=1}^{K} S_k \times GE_k(1) \quad (5)$$

where S_k is the share of total income held by subgroup k; $GE_k(1)$ measures the inequality for subgroup k and can be calculated as if the subgroup was a separate population. Meanwhile, $GE_b(1)$ is calculated assuming every person in a subgroup k obtains the mean income, m_k.

The application of Lorenz curve and Gini index in quantifying green space can be found in the work of Wu et al. (34) measuring the inequality of effective green equivalent distribution across the urban area in Beijing. However, the Theil index is more advantageous than the Gini index because of its decomposability. This paper will employ Theil index to geographically compare green space supply in Wuhan to a broad measure of demand (different age groups, migrants, and employment distribution) and decompose this index in different regions of Wuhan (the inner, middle, and outer areas) to compare the spatial equity of urban green space.

The Geographic Detector Analysis

Spatial stratified heterogeneity is the spatial expression of natural and socioeconomic process, which is an important approach for human to recognize nature. Geographic detector analysis is a new statistical method to detect spatial stratified heterogeneity and reveal the driving factors behind it. The study area is characterized by spatial stratified heterogeneity if the sum of the variance of subareas is less than the regional total variance, and if the spatial distribution of the two variables tends to be consistent, there is statistical correlation between them. Q-statistic in geographic detector analysis has been widely applied in many fields of natural and social sciences.

Here, the geographic detector analysis is utilized to detect spatial stratified heterogeneity between urban green spaces and socio-economic variables. The determinant power of covariate X to the spatial pattern of urban green spaces, or the q statistics, is

TABLE 2 | The Theil index of various green spaces in the inner, middle, and outer areas of Wuhan.

Type	PS	CR
Overall	0.29	0.09
Between group	0.05	0.02
Within group	0.24	0.07
Inner area	0.17	0.12
Middle area	0.37	0.03
Outer area	0.50	0.04

PS denotes park supply index; CR means the coverage ratio of urban vegetation.

defined as follows:

$$q = 1 - \frac{SSW}{SST} \tag{6}$$

$$SSW = \sum_{h=1}^{L} N_h \sigma_h^2, \quad SST = N\sigma^2 \tag{7}$$

where $h = 1, 2, \ldots, L$ is the strata of variable Y or covariate X; N_h is the number of strata h; N is the number of spatial units; σ_h^2 and σ^2, respectively, refer to the variance of Y in strata h and the whole region. SSW is the within sum of squares whereas SST is the total sum of squares. The q statistics ranges between 0 and 1. A larger value of q statistics indicates the better explaining power of covariate X on the distribution of Y.

RESULTS

Horizontal Equity Across All Population

Table 2 demonstrates the decomposable Theil index of various green spaces in Wuhan. Theil coefficients of PS and CR were 0.29 and 0.09, demonstrating that the overall supply of public parks is far more unequal across *jiedao*s of Wuhan than urban vegetation coverage. Residents in Wuhan tend to equally enjoy the psychological and biodiversity benefits from the mixed and woody vegetation. However, residents in Wuhan cannot enjoy equally the recreation and the related health benefits from the parks, mainly depending on their socio-economic status.

To detect the influence of spatial circular structure on the provision of green spaces, we decompose the overall Theil index across *jiedao*s by three groups, namely, Inner area, Middle area, and Outer area. As seen in **Table 2**, the Theil index of PS and CR within groups arrives at 0.24 and 0.07, whereas the Theil index of PS and CR between groups is only 0.05 and 0.02. Therefore, the inequitable distribution of parks as well as mixed and woody vegetation is mainly demonstrated within the inner, middle, and outer areas.

Moreover, the Theil indices of PS within the Inner area, Middle area, and Outer area are 0.17, 0.37, and 0.50, respectively. The distribution of public parks is more inequitable in the outer area than both the inner and middle areas. Residents living in the urban core are more likely to enjoy the recreation and health benefits from public parks where residents living in the urban suburb are unable to enjoy the corresponding benefits, depending on their socio-economic status. Meanwhile, the Theil indices of CR within the Inner area, Middle area, and Outer area are 0.12, 0.03, and 0.04. The distribution of mixed and woody vegetation is relatively equitable in the Inner, Middle, and Outer areas.

Due to the ongoing housing reform and the massive process of urban sprawl, residential spaces in urban China are changing from largely mixed work-unit compounds toward differentiated commercial neighborhoods (35). Due to historical reasons of urban development in China, the work-unit compounds were equipped without landscape greening and they are mainly distributed in the urban core. The local government was responsible for constructing parks to satisfy residents' demand for leisure activities. Thus, the park supply in the inner area is relatively equitable. However, as a result of housing reforms and marketization, the commercial neighborhoods provided by the real estate developers, are equipped with good greening environment and are mainly distributed in the middle areas and urban suburbs. Therefore, the number of parks constructed by the municipal government is only a few, resulting in the largely unequal distribution of parks especially in urban suburbs and exurban zones.

Mapping Horizontal Equity Gaps

Figure 3 demonstrates the spatial pattern of PS, CR, and population in Wuhan. Overall, the Inner area has higher PS, indicating that more public parks are concentrated in the city core. However, the middle and outer areas have higher CR, whereas the inner area is relatively lacking of mixed or woody vegetation. The distribution of population also demonstrates significant spatial variations. More population are clustered in the educational and high-tech town of Wuchang because many universities and high-tech enterprises are situated there to attract many college students and employees in the field of information and computer technology.

Figure 3 presents the distributions of *jiedao* units by population, PS, and CR quartiles. 34.83% of spatial units have high population yet low PS whereas 37.05% of spatial units have low population yet high PS, indicating that almost 40% of *jiedao*s in Wuhan suffer from the shortage of public parks. Moreover, 32.58% of spatial units have high population yet low CR whereas 24.72% of spatial units have low population yet high CR, indicating that more than 30% of *jiedao*s in Wuhan encounter the shortage of mixed or woody vegetation.

Figure 4 also illustrates spatial units in the most and least desirable quartile for each attribute: "Sweet-spot" spatial units have a high supply of green spaces and have a low population; "sour-spot" spatial units are the opposite (low green spaces, high population). We observed from **Figure 2** that the sweet-spot neighborhoods are mainly distributed in the old work-unit compounds nearby the location of the provincial and municipal governments in the inner area. On the one hand, these sweet-spot neighborhoods have easier accessibility to nearby public parks and the street sides were planted with woody trees having been growing for decades. On the other hand, as the old resident quarters, these sweet-spot neighborhoods are supplied with aging municipal public infrastructure and lack of public services. Since 2016, the Chinese government has paid attention

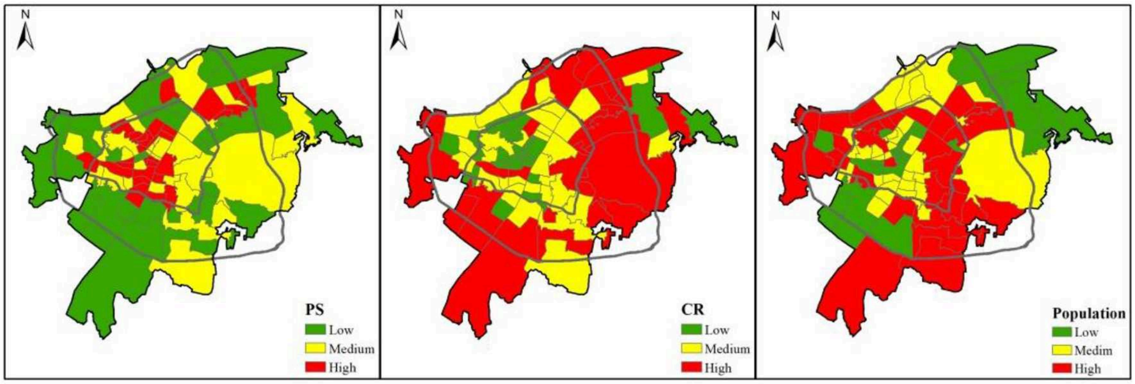

FIGURE 3 | The spatial pattern of PS, CR, and population in Wuhan.

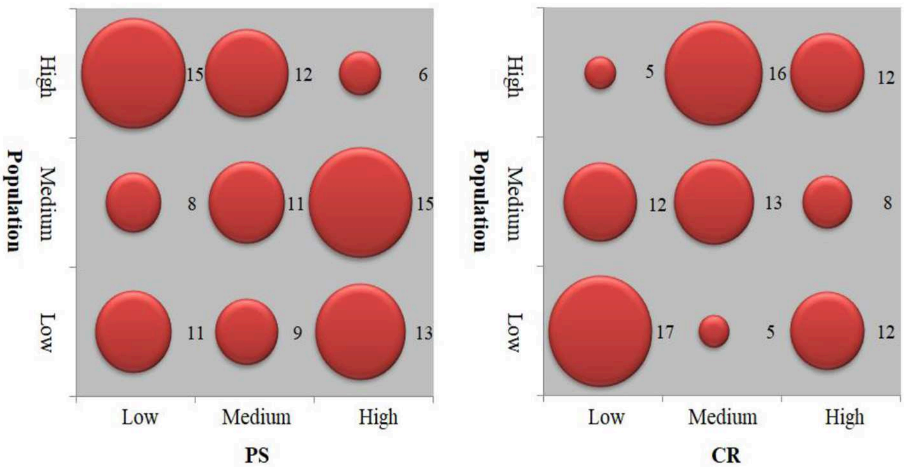

FIGURE 4 | Percentage of *jiedao* units in each population, PS, and CR quartiles. Values in each panel total 100%.

to urban redevelopment and advanced some reform policies to the reconstruction of these old residential quarters.

On the contrary, the sour-spot neighborhoods are mainly distributed in the newly developed commercial residences in the middle or outer areas. These sour-spot neighborhoods are mainly equipped with private gardens within the gated communities provided by estate developers. Usually, high-income residents are more likely to enjoy better greening environment and the corresponding benefits.

The Spatial Relation Between Socioeconomic Contexts and Urban Green Spaces

The geographic detector tool is employed to examine how socioeconomic contexts and social groups have influence on the distribution of public parks and mixed or woody vegetation. As seen in **Table 3**, the proportions of different social groups have differing explaining power on the distribution of public parks. First, the influence of education on the distribution of public parks is statistically significant at the 1% level. The spatial heterogeneity of education has more than 20% of explaining power on the spatially differentiated distribution of public parks. Therein, Prop Edu_mid has the largest explaining power (30%) on the distribution of public parks. Second, the influence of gender on the distribution of public parks is not statistically significant. Third, Prop Age below_15 and Prop Age above 65 have, respectively, 28 and 27% of explaining power on the distribution of public parks. This indicates that families with teenagers or elder people tend to reside in nearby public parks. Fourth, the importance of *hukou* is not statistically significant for explaining the distribution of public parks. Neither local residents nor migrants have preferences on living nearby public parks to enjoy the health benefits. However, the influence of different social groups on mixed or woody vegetation is not statistically significant.

Population density, as a proxy for the built environment, also clearly plays a role in the distribution of both public parks and urban vegetation. The spatial pattern of population density, respectively explains 31% of the distribution of public parks

TABLE 3 | The *q* statistics between urban green spaces and different population groups.

Type	Variables	PS	*P*-value	CR	*P*-value
Education	Prop Edu_low	0.21	0.05	0.24	0.79
	Prop Edu_high	0.30	0.03	0.25	0.36
	Prop Edu_uni	0.20	0.08	0.21	0.37
Gender	Prop female	0.15	0.51	0.10	0.99
	Prop male	0.18	0.27	0.08	0.97
Age	Prop age below_15	0.28	0.01	0.20	0.69
	Prop age 16–64	0.16	0.18	0.23	0.53
	Prop age above 65	0.27	0.01	0.16	0.65
Hukou	Prop local	0.14	0.41	0.13	0.82
	Prop migrants	0.14	0.39	0.14	0.83
Population density	0.31	0.01	0.47	0.00	
Per capita income	0.26	0.01	0.13	0.76	

PS denotes park supply index; CR means the coverage ratio of urban vegetation.

and 47% of the distribution of urban vegetation. This supports the theory that urban green spaces originate from the social need to improve their living environment. On the one hand, the government tends to build more public parks and plant more urban vegetation in densely populated areas to satisfy residents' need for better greening environment. On the other hand, the neighborhoods with well-provided public parks and urban vegetation become attractive and then draw more residents to live in this neighborhood.

Per capita income is statistically significant and could explain 26% of the distribution of public parks. However, per capita income is not significantly associated with mixed and woody vegetation. This proves that people with higher income tend to live nearby public parks and enjoy the recreation and health benefits. The positive association between per capita income and the supply of parks indicates that the greening of neighborhoods may cause and/or enhance gentrification, which is a social equity problem because it pushes out low-income residents in favor of high-income in-migrants (36). When green gentrification follows, it leads to increased concentrations of wealthy people living along the parks.

Vertical Equity for Different Social Groups

As demonstrated in **Figure 5**, urban green space supply is highly skewed toward the inner and outer areas. Regarding the park supply, all social groups in the inner area enjoy more green space supply than the other two areas. This suggests some vertical equity "advantage" of park supply for vulnerable social groups in the urban core. Regarding the urban vegetation supply, the urban outer area is equipped with more green space to all social groups than other areas, implying a degree of vertical equity "advantage" in the urban suburb.

Table 4 demonstrates the Theil indices for vulnerable groups in the inner, middle, and outer areas. High values of Theil indices indicate the highly inequitable supply within three regions of Wuhan for each vulnerable group. Therein, regarding the park supply, the inner area has the highest Theil index for females, residents with low education, children, and the elder whereas the outer area has the highest Theil index for the migrants. Regarding the coverage rate of urban vegetation, the outer area has the highest Theil index for all vulnerable groups. This indicates that unequal recreation and health benefits are provided for these vulnerable groups especially in the inner area, whereas these vulnerable groups get unequal access to mixed and woody vegetation to enjoy the psychological and biodiversity benefits especially in the outer area.

The inequitable supply of urban green spaces for vulnerable groups especially in the inner and outer areas can be attributed in the following two aspects: first, the greening initiatives in the inner area, such as renovation of old residential areas and constructing pocket parks contribute to environmental sustainability and economic sustainability, but not social sustainability. The greening of neighborhoods prepares them for gentrification, which allows elites (politicians and real estate developers) to benefit (36). Second, the coalition of real-estate developers and political elites transforms the brownfields in the outer area into residential neighborhoods with good environmental amenities. Through real-estate development associated with the greening, the green growth machine turned a profit and demographically transformed neighborhood through this process of green gentrification (37).

DISCUSSIONS

The inequity of urban green spaces is mainly demonstrated in terms of public parks instead of mixed or woody vegetation. This finding also highlights that the ecosystem services provided by urban vegetation are more equitably distributed, with recreational benefits provided by public parks being differentially distributed. This finding is in contrast to the empirical evidence on 10 U.S. cities that parks are more equitably distributed and that the increased inequity observed in the mixed and woody vegetation may be due to vegetation located on private land or streets (9). However, in the background of the socialist marketization with Chinese characteristics, urban green spaces as a public product are mainly planned and managed by the local government, which prefers to plant more trees instead of constructing parks.

Through the decomposable Theil index, the circular spatial structure has significant influence on the equity of urban green spaces. Therein, the distribution of public parks is more inequitable in the outer area, whereas the mixed and woody vegetation is more spatially differentiated in the inner area. The spatial equity of urban green spaces are closely associated with the ongoing housing reforms toward marketization and the massive process of urban sprawl, which may further enhance the inequity of greening environment in the urban China (17). Usually, high-income residents tend to live in the neighborhoods with private gardens within the gated communities provided by estate developers and enjoy better greening environment as well as corresponding benefits.

This paper confirms that there is widespread evidence of green inequity, supporting theories of environmental justice and

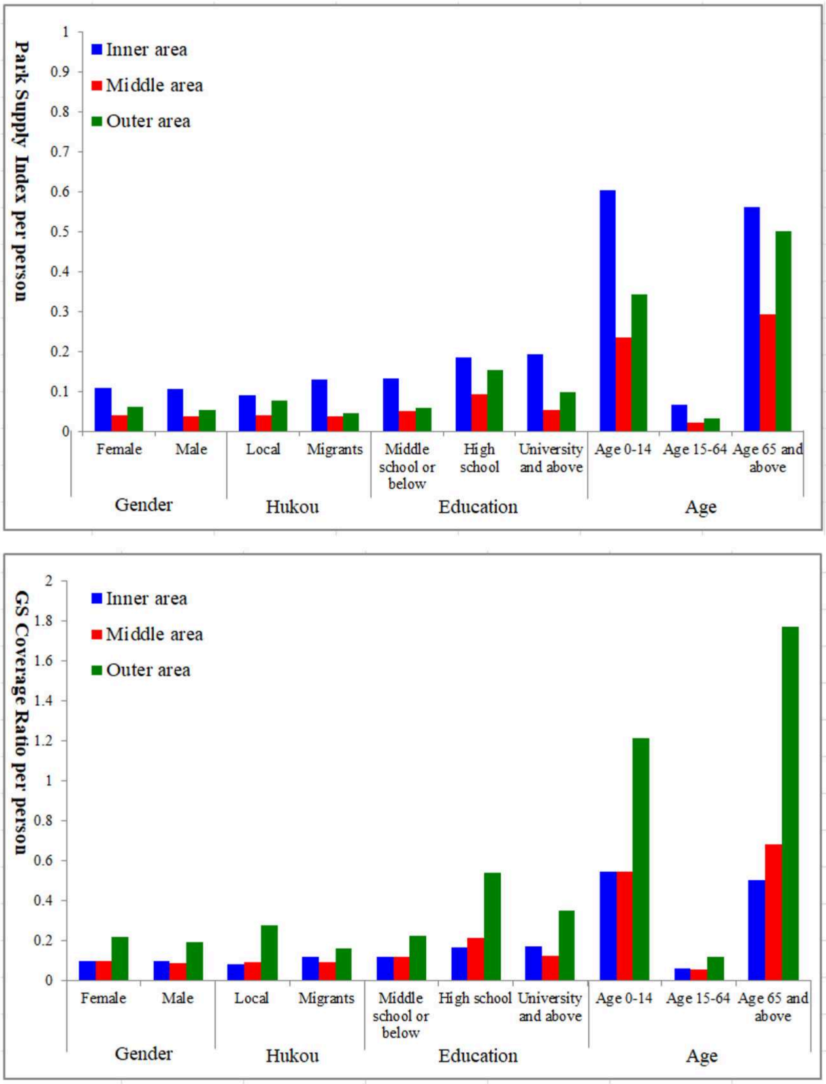

FIGURE 5 | Vertical equity of urban green spaces.

political ecology that suggest that environmental amenities are inequitably distributed across different social groups (9, 17). Neighborhoods with education above high school and more proportion of children and elder people are often associated with increased access to parks. Younger dwellers tend to prefer ecosystem services facilitating social interactions whereas older inhabitants prefer ecosystem services related to nature experiences (38). These diverging perceptions should be taken into account through urban development strategies to create a socially just and sustainable city in the face of global environmental changes.

Per capita income clearly plays a role in the distribution of parks, suggesting that environmental amenities are inequitably low in communities with lower economic power (39). Higher incomes are often associated with increased access to resources in society, while lower incomes are often associated with deprivation (28). Environmental amenities draw in wealthier groups of residents and push out lower-income residents, thus creating gentrification (36). Policy interventions are required in China to reduce environmental inequality brought by urban greening.

Although there is some evidence of vertical equity advantages for vulnerable groups with more parks supply in the inner area and more urban vegetation in the outer area, the highly internal differences of urban green spaces within the inner, middle, and outer areas should be noted. These vulnerable groups tend to gravitate toward different types of housing and location, leading to differing opportunities to enjoy the corresponding health benefits. How to incorporate the demand of vulnerable groups in the planning of green infrastructure becomes important to promote social justice and urban sustainability.

TABLE 4 | Theil indices for vulnerable groups in the inner, middle, and outer areas.

Type	PS			CR		
	Inner	Middle	Outer	Inner	Middle	Outer
Female	0.85	0.47	0.84	0.46	0.23	0.74
Migrants	0.50	0.65	0.86	0.33	0.34	1.26
Edu_low	0.82	0.47	0.76	0.55	0.42	0.67
Children	1.03	0.46	0.72	0.58	0.39	0.64
The elder	1.29	0.44	0.44	0.71	0.35	0.77

PS denotes park supply index; CR means the coverage ratio of urban vegetation.

CONCLUSIONS AND POLICY IMPLICATIONS

This paper aims to enrich the empirical analyses of green space equity with a case study of an inland city of China. Two contrasting perspectives are compared to examine the horizontal and vertical equity of public parks and urban vegetation. The decomposable Theil index is employed to investigate the influence of circular spatial structure on the equity of green spaces. Through mapping horizontal equity gaps, we can observe the sweet spot and the sour spot of green spaces. Then, the geographic detector analysis is utilized to examine their spatial relation between socioeconomic contexts and urban green spaces. The following conclusions can be drawn:

First, the inequity of public parks is more intense than mixed and woody vegetation. The influence of circular spatial structure on the distribution of parks is inevitable that the outer area has higher inequity of the park supply than the inner and middle areas. Second, socioeconomic variables, such as education, age, population density, and per capita income demonstrate significant impact on the distribution of parks. However, only population density shows close association with the distribution of mixed and woody vegetation. Third, urban green space supply is highly skewed toward the inner and outer areas. Vulnerable groups, such as females, residents with low education, migrants, children, and the elder have inequitable opportunities to enjoy the health benefits of parks and vegetation especially in the inner and outer areas.

The above findings shed some important insights into urban sustainability and promoting social and environmental justice. The inequitable distribution of green spaces implies that policy interventions are required to reduce environmental inequality. The spatial factor is important to guide the spatial equity of green spaces that the outer area has more shortage of public parks than the inner and middle areas. Micro-sized green spaces, such as pocket parks are recommended in urban suburbs to improve residents' access to green spaces. The social factor is also significant for urban planners and policy-makers to promote environmental justice. This paper confirms that environmental amenities are inequitably distributed across different social groups. The diverging perceptions of various social groups should be taken into account through urban development strategies to create a socially just and sustainable city in the face of global environmental changes. Furthermore, green gentrification in urban China may enhance the inequity of greening environment. The top-down process of green space management in China tends to allow elites and politicians to enjoy the green benefits. Creative governance of urban green space, such as shared governance involving multiple stakeholders is proposed to provide a cooperative atmosphere for decision making and active citizenship through volunteering.

There are two limitations of this study. The dimension of equity includes equity of opportunity and equity of outcome. This paper mainly focuses on the former but ignores the latter. Further studies could compare the differences between equity of opportunity and equity of outcome for urban green spaces. Moreover, this paper presents a novel method combining proximity and quality to measure the spatial supply of urban parks. The advantage of the proposed method in this paper is its relative simplicity to assess the spatial supply of public parks although the calculation of the park supply index is somewhat limited since it does not measure the access to specific destinations and only considers the walk catchments.

DATA AVAILABILITY STATEMENT

The datasets analyzed in this article are not publicly available. Requests to access the datasets should be directed to sanwei.87@163.com.

AUTHOR CONTRIBUTIONS

SH: designing the manuscript, and structure and writing the manuscript. YW: data processing and map designing. LW: indicator calculation and result analysis.

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Evaluating Cultural Ecosystem Services of Urban Residential Green Spaces From the Perspective of Residents' Satisfaction With Green Space

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Green spaces in residential areas provide multiple cultural ecosystem services (CES), which can contribute to human health by increasing the frequency of residents' visits. We evaluated the CES of residential green spaces by assessing residents' satisfaction with these spaces in the city of Zhengzhou, China. The data reveal the supply capacity of CES in residential green spaces: the results suggest that the level of recreational services is low, whereas the residents' satisfaction with the sense of place and neighborhood relations is high. The lower the frequency of residents who visit a park outside the residential area, the higher the satisfaction with the CES. This suggests that residential green spaces can effectively compensate for the lack of nearby parks owing to their proximity to residents' living quarters. The CES in residential communities increased as vegetation coverage increased, indicating that natural vegetation is a source of CES. In addition, the results showed that residents' perceptions of plant decoration, landscape patterns, and management and infrastructure in particular can effectively improve the level of CES, and this could compensate for CES that have shrunk owing to low green space coverage. This study has practical significance and value for the planning and design of residential green spaces, offering suggestions for urban landscape planners and decision makers. Future research should combine the residents' perception of demand and supply of CES and should clarify the gap and trade-off between them.

Keywords: cultural ecosystem services, residential districts, green space, satisfaction, physical environment

INTRODUCTION

The ecosystem services of urban green spaces can be defined as services that improve the welfare of urban residents who enjoy green spaces (1). These services include support, regulation, supply, and cultural ecosystem services (CES) (2). CES can be provided by green spaces for leisure, tourism, cultural education, aesthetic appreciation, and spiritual needs (3), all of which account for a large proportion of the ecosystem services in an urban green space (4). Residents' physical and mental health, especially social belonging, group identity, and social integration, are closely related to environmental services (5). In recent years, CES have become a trending topic in urban ecosystem services research. However, compared with other types of ecosystem services, research on CES is still in its infancy because its intangible characteristics are difficult to quantify.

Currently, several researchers are exploring various means to study the CES of urban green spaces (6–13). Survey questionnaires, the most commonly used evaluation method, can be direct or indirect. Direct methods includes face-to-face (5, 6), email (7, 8), or network (9, 10) surveys, which evaluate CES according to residents' visit frequency to green spaces, activity types, and perceptions of CES. Indirect methods capture pictures of the target place and then invite residents to give scores to the CES reflected by the different green space landscapes or land use types in the pictures (11, 12). Although face-to-face questionnaires are an effective way to evaluate urban ecosystem services, they are also difficult, mainly because of the high cost (8).

Previous studies have quantified CES in green areas from the residents' perceptions (10, 13), producing CES scores for subjective cognition and distinguishing the importance of different CES (9, 14–16). Moreover, by detecting the population's perspective on need, this research has described the demand for CES. The trade-off between the demand and supply of CES is also a popular research topic that can provide constructive suggestions for urban management and planning. CES supply in urban areas is characterized by the spatial distribution and physical attributes of urban green spaces, such as the amount, size, type, water bodies, facilities, and biodiversity (17). Residents' satisfaction with their surrounding physical environment is commonly used in studies concerning the well-being of humans (18, 19); such parameters objectively portray the status (i.e., positive or negative) of an urban environment from the residents' perspective. Therefore, the evaluation of residents' satisfaction with CES can directly present the supply capacity of CES, which will facilitate any adjustment of the physical characteristics of green spaces. However, few studies have assessed CES from the perspective of residents' satisfaction with green spaces.

Urban residents around the world express a desire for contact with nature and one another, including attractive environments, recreational and play areas, privacy, active roles in the design of the community, and a sense of community identity (20). A positive correlation exists between human health and urban green spaces (21–23). Urban green spaces refer to natural vegetation in cities, including highly artificial green spaces, such as roadside green parks, residential green space, and natural woodland, which provide a variety of ecosystem services, especially recreational and entertainment areas with CES. Numerous studies have focused on the CES of urban parks, forests, wetlands, and other popular green spaces (6, 24, 25), whereas residential areas have received minimal attention. With the rapid expansion of cities and resultant growth of the urban population, as well as the limited natural vegetation in cities, urban residential areas are becoming gradually dominated by environments that have a high population density and a low green space density. In particular, the green areas of urban residential areas in developing countries are often correlated with real estate prices (26), which leads directly to the prevalence of urban human settlements and environmental inequity (27). Scholars have therefore pointed out that the remaining green spaces should make up for the shortage of other green land types, such as roadside and residential green spaces (9). The distance between urban green spaces (e.g., parks) and residents determines the use frequency of these spaces (10, 28, 29). Residential green spaces are the most common and frequently used land types and have multiple ecosystem functions and services (e.g., biodiversity protection, climatic adjustment, energy saving, and recreation). Therefore, evaluating and exploring the CES characteristics of green areas in high-density residential areas can provide valuable references for urban ecosystem research. As an essential component of urban green spaces, residential green spaces are characterized particularly by high fragmentation and heterogeneity, and huge differences exist among residential districts, which are correlated with various landscape planners, property managers, and residents with different socioeconomic status. Hence, research on CES in urban residential green spaces is difficult to conduct. Many studies have reported that the design of urban landscapes greatly influences the well-being and behavior of users and nearby inhabitants (18, 30). CES in high-density residential areas are thus more important than the regulative and supporting services of green spaces. Moreover, magnifying the CES in limited spaces is significant. Investigating and assessing CES in residential areas can further enrich the theories and practices of ecosystem services in urban green spaces.

The influencing factors of CES in urban green spaces are a key research topic, which could provide important and practical information for the planning and management of urban green spaces. The CES in urban green spaces are often related to residents' socioeconomic status (e.g., age, income level, marriage, and profession) (14, 31–34). Specifically, residents' socioeconomic status is closely related to the subjectivity and intangibility of CES. In addition, urban morphologies and land use may affect CES in large-scale green spaces. For instance, CES in wetlands are better than in other land types (9, 35). The quality and quantity of green space landscapes are the important influencing factors of CES (36), along with green space size (37), green space accessibility (38), natural properties of green spaces (9, 14, 39), and species composition and biodiversity (40, 41). Studies have found that cleanliness and proper management (9), as well as infrastructure (42), contribute greatly to improvement of CES in green spaces. Green spaces in residential areas offer various CES, such as walking, exercise, aesthetic appreciation, neighborhood exchanges, stress-relieving activities, and activities that foster a good mood. Hence, exploring the influencing factors of CES in residential green spaces should provide important practical guidance for landscape planning and the design of green spaces in residential areas.

Previous studies have focused on residents' satisfaction with their living environment (10, 14, 33, 42). Physical and natural environments exert significant effects on residential satisfaction with the aspects of the natural environment, convenient transportation, environmental health, urban security, the convenience of public facilities, and the sociocultural environment. However, the following questions remain: (1) How does the natural environment affect the human perspective of the residential environment? (2) How satisfied are people with urban green spaces in residential areas? (3) What is the current level of CES in the residential green spaces of high-density communities? (4) Is the vegetation coverage of green spaces a major factor that affects CES? (5) What physical environment of residential green spaces contributes the most to CES? These questions can be answered by evaluation of CES and exploration of the possible determinant factors of CES in residential green spaces.

This study aimed to evaluate the level of CES in green spaces of residential areas by examining the satisfaction of residents and to explore the possible factors affecting the function of residential green spaces (e.g., coverage of green space in the residential areas, social factors, residents' use of green spaces, and management) and the key issues that should be addressed.

MATERIALS AND METHODS

Study Area

A total of 40 residential communities in Jinshui District, Zhengzhou City, Henan Province, China, comprised the study area. Zhengzhou, the capital of Henan Province, is Henan's largest and most populated city and has an area of 7,446 km^2 and 9.88 million inhabitants as at 2018. Most housing estates in the Jinshui District are relatively mature, containing not only medium vegetation coverage but also housing built before 2010. We assumed that these housing estates would provide a stable and objective level of CES.

Among the 40 major cities in China, Zhengzhou has the highest population density at 15,000 people/km^2, and the urban land conflict is most prominent. The current urbanization rate of Zhengzhou is 78.2%, ranking 30th in China, and the urbanization process in this city is advancing rapidly. Many real estate resources have been built, but their overall quality is low. In particular, Zhengzhou has low green space coverage and property management with different levels. Gaps between the living environment of Zhengzhou's urban residents and other first-tier cities in China (e.g., Beijing, Shanghai, Shenzhen, and Guangzhou) are evident; that is, Zhengzhou lags behind in terms of urbanization and economic development. Evaluating the current supply capacity of the CES of residential areas can provide a scientific reference for improving the living environment and well-being of Zhengzhou residents.

Zhengzhou is divided into six administrative districts and seven provincial direct counties. Jinshui District is one of the most economically developed urban areas in the province, with a total area of 135.3 km^2 and a population of 1.402 million. Jinshui District is the area with the largest population and the most developed economy in Zhengzhou (**Figure 1**). Compared with the other districts' residential areas, the real estate development area in Jinshui District is the largest, earliest, and most mature. The residential projects developed in the Jinshui District are composed of 50% ordinary housing and almost 40% villas and affordable housing. These patterns are closely related to the comprehensive functions undertaken by the Jinshui District and the spatial development strategy of "Northward and Eastward Expansion." The dominant type of residential area in the Jinshui District is the reason why this area was chosen for the case study (43).

Jinshui District is also the most active urban expansion area in Zhengzhou. The demand for residential areas from the urban population is increasing, leading to development of high-density residential areas in the region at the expense of green spaces and a reduction of ecosystem services.

Classification and Evaluation Indicators of Cultural Ecosystem Services in Green Spaces in Residential Areas

CES can be classified under the non-material benefits provided by ecosystems (44). CES in urban green spaces are globally categorized into seven types: aesthetic information, recreation, cultural heritage, education, social relations, health, and spiritual/religious values (2, 45, 46). In residential areas, CES could be defined as opportunities for residents to enjoy recreational activities, aesthetic appreciation, social contact with neighbors, and stress-relieving activities and to strengthen the sense of belonging. CES in residential green spaces are divided into five types: recreation, aesthetics, social relations, a sense of belonging, and spiritual demand (**Table 1**). Recreational services refer to various recreational activities available in the residential green space for the residents, including exercise, walking, dog walking, childcare, and running. Recreational services are evaluated by measuring the frequency and duration of residents' participation and their satisfaction. Aesthetic services are residents' aesthetic perceptions of the overall landscape and plant collocation in residential green spaces, and they are evaluated by the residents' overall satisfaction with the aesthetics of the above two factors. Social relations services provide residents with opportunities to communicate with neighbors and release emotional stress. This service is evaluated through the communication frequency of residents with family members, friends, or neighbors, as well as their satisfaction with neighborhood relations. The evaluation index for the sense of belonging involves residents' satisfaction with respect to how welcoming and nurturing the environment is. Finally, spiritual services involve spiritual experience and spiritual release in residential green spaces. The evaluation indexes for spiritual services include satisfaction with pressure relief features and the quietness of the environment. The quality of urban green spaces is widely evaluated by residents' satisfaction with various functions (15, 19, 34). Therefore, in our study, we applied the satisfaction with CES to identify the level of CES.

Data Collection

A face-to-face survey was used to explore the attitudes of residents in Zhengzhou City toward the different types of CES in the residential green spaces. To ensure the adequacy of the sample size, as well as the authenticity of the questionnaire, we selected 40 sites from the 215 residential communities in Jinshui. These sites, all of which were built after 2000, have at least 600 households. The area of the 40 residential estates ranged from 0.38 to 33 hm^2, and the vegetation cover ratio was between 13 and 58%. In China, a residential community is the smallest

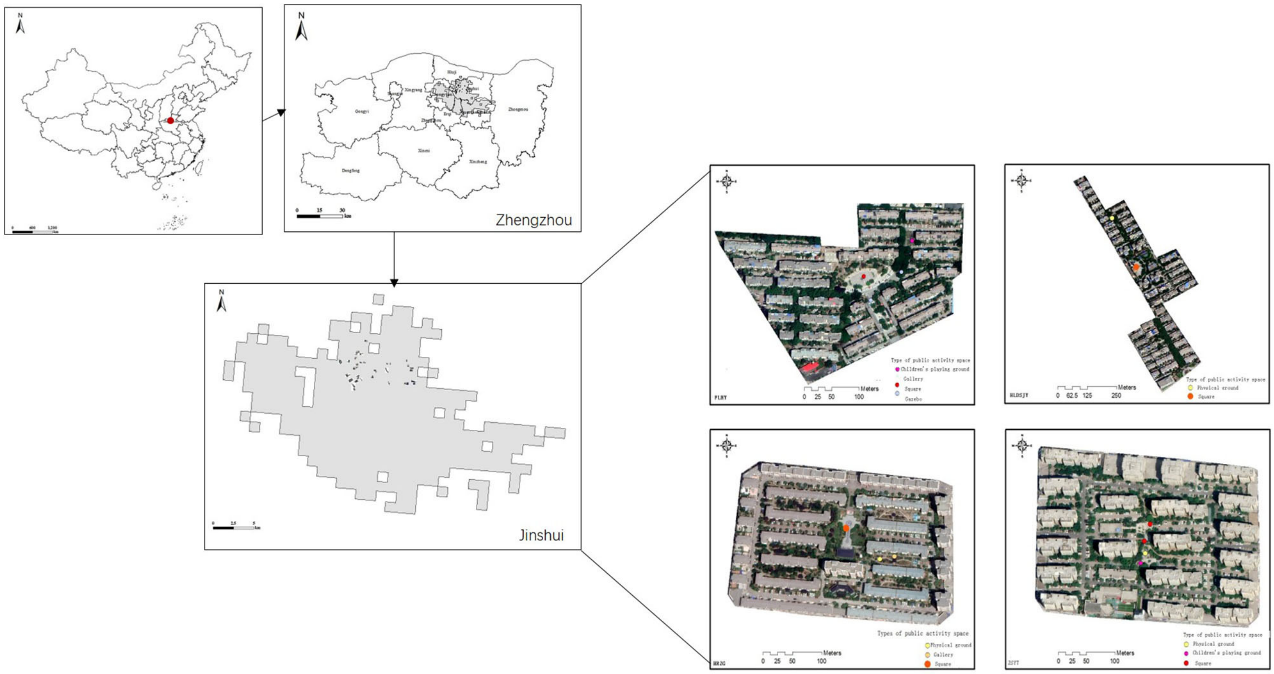

FIGURE 1 | The geographical locations of the selected 40 residential communities.

TABLE 1 | Selected CES and their indicators.

CES	Indicators
Recreation	Visiting types, visiting frequency, residence time, and satisfactory recreation
Aesthetic value	Satisfactory aesthetic of the green space landscapes and plant collocation
Social relationship	Chat frequency, satisfactory neighborhood relation
Sense of belonging	Satisfactory sense of belonging
Spiritual value	Stress relieving features, Quietness of the environment

residential unit within a limited space (**Figure 1**). Each residential community has unique characteristics, such as vegetation coverage, water bodies, public activity spaces, management, infrastructure, vegetation structure, and plant species. Moreover, different communities are relatively independent and closed. Therefore, our study investigated residents' overall satisfaction with different types of CES and the use of green spaces in these sites.

To truly express the impact of green spaces on residents' activities, the data were collected on weekends and official holidays from June 2017 to August 2018. The survey was conducted between 09:00 and 19:00. Our interviewees were mainly residents who are inactive in the green spaces of the community. A household survey was used as a supplement to ensure a sufficient sample size. A total of 4,519 respondents were interviewed, with between 93 and 135 interviewees from each of the 40 communities. First, residents' use of green spaces and satisfaction with different types of CES were collected to evaluate the cultural service levels of the green spaces. Then, the residents' satisfaction with green space management and infrastructure was investigated. Finally, the most satisfying and unsatisfying factors with regard to the residential green spaces were collected, covering management, water services, public activity spaces, green coverage, facilities, plant collocation, and the landscape pattern of the green spaces, to analyze the subjective physical environment of the residential areas by investigating the influencing factors of CES in the residential green spaces. The collected physical environment indicators included real vegetation coverage, the number of public activity spaces, including the existence of water bodies, and the management level. With the use of Google's high-definition imagery, object-oriented automatic classification was applied to extract the real vegetation coverage, which refers to the vertical projection area of vegetation (including leaves, stems, and branches) on the ground as a percentage of the total area of the residential area. The number of public activity spaces (e.g., squares, water bodies, children's play facilities, gazebos, promenades, and places for physical exercise) was obtained during the survey of residents' satisfaction with CES. A total of 40 residential areas were categorized into two groups: residential areas with water body settings and those without. The management of residential green spaces was subjectively divided into three levels: good, medium, and poor.

Data Analysis

All data aggregation and statistical analyses were conducted in Microsoft Excel and SPSS v21. First, we analyzed the descriptive statistics to explore the socioeconomic characteristics of the respondents (gender, age, income, education, and the use of residential green spaces) and their ways of using green areas (**Table 2**). The level of respondents' satisfaction with the various CES in the residential green spaces was scored 1–10, with 1 indicating poor satisfaction and 10 maximum. The overall satisfaction with CES was calculated as an average of satisfaction with seven types of CES, including recreation, the aesthetics of the green space landscapes and plant collocation, neighborhood relations, the sense of place, stress-relieving features, and the quietness of the environment. Pearson's correlation analysis was used to investigate the relationship among the various CES in the residential green spaces (Pearson's coefficient) (**Table 3**). Linear regression analyses were applied to test the possible variables affecting the level of CES. The analysis process was as follows (47): single-factor results were derived from a univariate linear regression model that included a single variable (**Table 4**), and significant variables emerging from the single-factor models ($p < 0.05$) were then included in subsequent multivariate linear models (i.e., social–economic attributes, green spaces' use, frequency of visits to parks outside the residential area, and the subjective and objective physical environmental variables) (**Table 5**), which were examined in a series of backward stepwise elimination procedures. The final multivariate linear regression models included all the demographic variables and the successive inclusion of significant variables from the socioeconomic factors, use of green space, and the physical environmental variables selected by the backward stepwise procedures ($p < 0.05$).

Ethics Approval

This study was carried out in accordance with the recommendations of the ethical standards of Henan University of Economics and Law. The protocol was approved by Henan University of Economics and Law. All subjects gave written informed consent in accordance with the Declaration of Helsinki.

RESULTS

Social and Economic Characteristics of the Respondents

Table 2 presents the demographic characteristics of the survey respondents and their mean satisfaction with the CES in their residential green spaces. A total of 4,519 residents in 40 residential areas were interviewed. The percentage of female respondents (50.28%) was slightly higher than that of the male ones (49.72%). Most respondents were within the age range of 30–39 years (24.36%), followed by 21–29 (19.7%), <20 (17.1%), 40–49 (15.17%), >60 (13.6%), and 50–59 years (10.07%). In terms of educational attainment, most of the respondents had an undergraduate degree (28.54%) or had completed junior high school or lower (27.73%), junior college (21.3%), or high school

TABLE 2 | Respondents' demographic characteristics and use of residential green spaces.

Characteristic	Frequency	Percentage (%)
Gender		
Male	2,247	49.72
Female	2,272	50.28
Length of study		
<1 year	663	14.68
1–3 years	1,105	24.45
3–5 years	1,019	22.54
>5 year	1,815	40.16
Age group		
<20	773	17.1
21–29	890	19.70
30–39	1,101	24.36
40–49	686	15.17
50–59	455	10.07
>60	615	13.6
Education		
Junior high school or lower	1,253	27.73
High school	816	18.05
Junior college	963	21.3
Undergraduate	1,290	28.54
Post-graduate	198	4.38
Income(RMB)		
No income	1,428	31.6
1,000–3,000	700	15.5
3,000–5,000	1,322	29.25
5,000–10,000	838	18.55
>10,000	230	5.1
Visiting frequency to parks		
Everyday	464	10.26
At least three times a week	1,101	24.37
At least three times a month	985	21.79
Occasional	1,969	43.58
Visiting frequency to residential green spaces		
Everyday	1,779	39.36
At least three times a week	1,395	30.87
At least three times a month	528	11.68
Occasional	817	18.07
Residence time(%)		
Half an hour	1,991	44.05
1–2 h	1,701	37.65
Never	383	8.48
3 h	267	5.91
>3 h	175	3.87
Chatting frequency(%)		
Everyday	1,263	27.95
At least three times a week	1,388	30.71
At least three times a month	523	11.58
Occasional	776	17.18
Never	568	12.56

TABLE 3 | Pearson's correlation coefficient of the different CES.

	Recreation	Aesthetic of the landscape	Aesthetic of plant collocation	Quietness	Neighborhood relation	Stress relieving	Sense of belonging
Recreation	1						
Aesthetic of the landscape	0.922**	1					
Aesthetic of plant collocation	0.924**	0.990**	1				
Quietness	0.931**	0.941**	0.944**	1			
Neighborhood relation	0.606**	0.538**	0.544**	0.599**	1		
Stress relieving features	0.920**	0.934**	0.930**	0.937**	0.689**	1	
Sense of belonging	0.914**	0.875**	0.889**	0.932**	0.754**	0.938**	1

**$p < 0.01$.

(18.05%). The smallest percentage of respondents had a post-graduate degree (4.38%). As for monthly income, respondents with no income represented the largest percentage (31.6%); followed by those earning 3,000–5,000 RMB (29.25%), 1,000–3,000 RMB (25.5%), and 5,000–10,000 RMB (18.55%); and last those earning above 10,000 RMB (5.1%). Almost half of the respondents had lived in the community area for more than 5 years (40.16%), followed by those residing in the area for 1–3 (24.45%) and 3–5 years (22.54%), and last those living in the community for <1 year (14.68%).

Cultural Ecosystem Services Satisfaction Levels in the Residential Green Spaces

Figure 2 shows the residents' satisfaction level with CES in the residential green spaces, which is based on the respondents' reported usage and satisfaction regarding residential green spaces. Satisfaction with neighborhood relations obtained the highest average score of 7.73 (from a scale of 1 to 10), followed by the sense of belonging (6.81), vegetation landscape aesthetics (6.62), and plant collocation aesthetics (6.56). Satisfaction with recreation services, the quietness of the environment, and stress-relieving features obtained the lowest average scores (6.36, 6.40, and 6.52, respectively). The average overall residents' satisfaction score was 6.71. These results reveal that the residents' satisfaction with various types of CES is relatively similar. The relationship between different CES of green spaces was analyzed using Pearson's correlation (**Table 3**), which revealed significant positive correlations ($p < 0.01$). The main activities of residents in residential green spaces include walking, childcare, and resting (**Figure 2**), which accounted for 48.24, 33.89, and 27.17% of the activities, respectively. In addition, residents exercise (18.47%), meet and chat with friends (10.56%), walk their dogs (7.34%), participate in cultural activities (e.g., singing, dancing, calligraphy, playing chess or cards, and painting) (5.69%), ride bicycles (4.04%), and drink tea (1.24%).

Residents frequently visit residential green spaces (**Table 2**). Approximately 40% of the interviewed residents visit residential green spaces every day, and 30.87% visit at least three times per week. In addition, 11.68% of residents visit residential green spaces at least three times per month, and 18.07% pay occasional visits. However, most residents stay in residential green spaces for a short time: 44.05% stay for nearly half an hour, whereas 37.65% stay for 1–2 h. The proportion of residents staying for a longer time than this is relatively low, with 5.91 and 3.87% staying for 3 and >3 h, respectively. Walking is the major activity of the residents who stay in the residential green spaces for 1–2 h, whereas engaging in social communications and drinking tea are the primary activities of residents who stay for roughly 3 h. Moreover, social communication is the reason why residents stay longer than 3 h.

A statistical analysis of the residents' frequency of communicating with neighbors and friends in the residential green spaces was also performed. The results returned a high overall frequency: 27.95 and 30.71% of the residents chat with others every day and at least three times a week, respectively, and 11.58% chat with other people at least three times every month. Only 17.18 and 12.56% of residents occasionally and hardly chat with neighbors and friends, respectively. In addition, almost half of the respondents pay occasional visits to parks outside the residential areas (43.58%), whereas the lowest proportion visits these parks every day (10.26%). In addition, several people visit parks at least three times a week (24.37%) or at least three times a month (21.79%).

Determinants of Cultural Ecosystem Services in Residential Green Spaces

According to the univariate linear regression model between the socioeconomic characteristics and residents' satisfaction with CES (**Table 4**), gender, length of stay, and education background showed no significant correlations. Interestingly, the proportion of people in the age group 21–29 years was negatively correlated with multiple CES, whereas that in the age group 50–59 years was positively correlated with the satisfaction of neighborhood relations and sense of belonging, whereas the age group >60 years was significantly correlated with satisfaction with a quiet environment and a sense of belonging. With respect to income level, residents earning 1,000–3,000 RMB were only slightly satisfied with plant collocation aesthetics.

Most residents were dissatisfied with the management, water facilities, and the public activity spaces in the residential green spaces (**Figure 3**), accounting for 27.53, 19.10, and 14.44% of the total resident population. Moreover, 11.21, 6.89, 5.05, and 4.11% of the residents were not satisfied with the green space coverage, infrastructure, plant collocation, and landscape

TABLE 4 | Relationship between residents' satisfaction on different CES and demographic characteristics, use frequency of green spaces and variables of physical environment with the univariate linear regression analysis.

Variables	Recreational B (P)	Aesthetic B (P)	Quietness B (P)	Neighborhood relation B (P)	Stress relieving B (P)	Sense of belonging B (P)	The total level of CES B(P)
RESIDENTS 'DEMOGRAPHIC CHARACTERISTICS (%)							
Age group							
21–29 years	−0.47 (0.02)	0.06 (0.01)	0.05 (0.021)	−0.04 (0.004)	0.05 (0.009)	0.06 (0.002)	−0.05 (0.007)
50–59	0.05 (0.23)	0.09 (0.1)	0.08 (0.123)	0.06 (0.029)	0.08 (0.07)	0.09 (0.046)	0.07 (0.08)
>60	0.04 (0.151)	0.05 (0.117)	0.06 (0.041)	0.03 (0.07)	0.04 (0.103)	0.05 (0.042)	0.05 (0.07)
Income (RMB)							
1,000–3,000	−0.06 (0.08)	−0.08 (0.029)	−0.05 (0.218)	0.003 (0.895)	−0.05 (0.134)	−0.04 (0.254)	−0.05 (0.117)
RESIDENTIAL GREEN SPACES "USE"							
Visiting frequency							
At least three times a month	−0.004 (0.893)	0.02 (0.603)	0.01 (0.755)	−0.05 (0.021)	0.002 (0.953)	−0.017 (0.598)	−0.004 (0.889)
Residence time (%)							
Never	−0.074 (0.059)	−0.11 (0.02)	−0.08 (0.073)	−0.005 (0.854)	−0.05 (0.149)	−0.06 (0.148)	−0.06 (0.087)
1–2 h	0.04 (0.01)	0.04 (0.03)	0.04 (0.032)	0.02 (0.051)	0.04 (0.007)	0.03 (0.035)	0.037 (0.015)
Chatting frequency (%)							
At least three times a month	−0.009 (0.765)	0.002 (0.951)	−0.01 (0.699)	−0.04 (0.023)	−0.008 (0.756)	−0.03 (0.343)	−0.01 (0.617)
VISITING FREQUENCY TO PARKS OUTSIDE (%)							
At least three times a week	−0.03 (0.14)	−0.042 (0.078)	−0.04 (0.092)	−0.006 (0.645)	−0.04 (0.034)	−0.02 (0.246)	−0.03 (0.09)
At least three times a month	−0.04 (0.078)	−0.03 (0.197)	−0.04 (0.088)	−0.04 (0.004)	−0.04 (0.066)	−0.04 (0.056)	0.04 (0.062)
Occasional	0.03 (0.018)	0.03 (0.02)	0.03 (0.013)	0.01 (0.134)	0.03 (0.015)	0.02 (0.058)	0.026 (0.015)
PHYSICAL ENVIRONMENTAL VARIABLES (OBJECTIVE)							
Vegetation coverage ratio (%)	0.04 (0.02)	0.06 (0.002)	0.06 (0.001)	0.03 (0.001)	0.05 (0.003)	0.05 (0.002)	0.047 (0.003)
Level of management	0.68 (<0.001)	0.90 (<0.001)	0.76 (<0.001)	0.75 (<0.001)	0.61 (<0.001)	0.6 (<0.001)	0.653 (<0.001)
Number of spaces for public activities	0.09 (0.007)	0.13 (0.001)	0.11 (0.005)	0.04 (0.059)	0.10 (0.003)	0.1 (0.002)	0.098 (0.002)
Existence of water body	0.64 (0.036)	0.90 (0.011)	0.70 (0.045)	0.44 (0.021)	0.70 (0.02)	0.694 (0.02)	0.678 (0.016)
PHYSICAL ENVIRONMENTAL VARIABLES (SUBJECTIVE)-PROPORTION OF RESIDENTS WHO ARE SATISFIED WITH PHYSICAL ENVIRONMENT (%)							
Plant decoration	0.02 (0.017)	0.09 (<0.001)	0.08 (<0.001)	0.03 (0.022)	0.07 (<0.001)	0.04 (<0.001)	0.065 (<0.001)
Coverage of greenspaces	0.05 (0.012)	0.07 (<0.001)	0.06 (<0.001)	0.02 (0.035)	0.05 (<0.001)	0.045 (<0.001)	0.049 (<0.001)
Waterbody	0.05 (0.024)	0.05 (0.053)	0.06 (0.028)	0.002 (0.876)	0.03 (0.156)	−0.04 (0.017)	0.038 (0.069)
Space for public activities	−0.04 (0.056)	−0.07 (0.008)	−0.06 (0.013)	−0.025 (0.876)	−0.049 (0.024)	−0.04 (0.056)	−0.052 (0.012)
Landscape pattern	0.17 (0.005)	0.20 (0.003)	0.173 (0.009)	0.012 (0.755)	0.13 (0.018)	0.06 (0.001)	0.147 (0.007)

TABLE 5 | Effects of residents' socioeconomic attributes, use characteristic and physical environment of green spaces on the total level of CES with the multivariate linear regression analysis.

Variable	Model 1		Model 2		Model 3		Model 4		Model 5	
	Beta (CI)	*P*	Beta (CI)	*P*	Beta (CI)	*P*	Beta (CI)	*P*	Beta (CI)	*P*
OBJECTIVE PHYSICAL ENVIRONMENT										
Real vegetation coverage ratio	0.25 (0,0.05)	0.048	0.19 (−0.01,0.05)	0.169	0.21 (−0.01, 0.05)	0.152	0.22 (−0.01, 0.05)	0.154	0.21 (−0.01, 0.05)	0.171
Existence of water body					−0.07 (−0.63, 0.37)	0.598	−0.1 (−0.78, 0.43)	0.552	−0.09 (−0.79, 0.45)	0.577
Number of spaces for public activities							0.04 (−0.05, 0.07)	0.767	0.04 (−0.05, 0.07)	0.777
management level									−0.04 (−0.41, 0.34)	0.8437
SUBJECTIVE PHYSICAL ENVIRONMENT										
Landscape pattern	0.28 (0.02, 0.18)	0.015	0.24 (0, 0.17)	0.061	0.24 (−0.01, 0.17)	0.065	0.24 (−0.01, 0.18)	0.071	0.25 (−0.01, 0.19)	0.089
Plant decoration	0.26 (0, 0.06)	0.053	0.28 (0, 0.06)	0.045	0.28 (0, 0.06)	0.05	0.27 (−0.003, 0.06)	0.078	0.27 (−0.004, 0.06)	0.085
Coverage of greenspaces			0.13 (−0.02, 0.04)	0.436	0.14 (−0.02, 0.04)	0.41	0.13 (−0.02, 0.04)	0.474	0.14 (−0.02, 0.04)	0.467
Space for public activities	0.28 (0.02, 0.18)	0.015	−0.14 (−0.06, 0.02)	0.297	−0.13 (−0.06, 0.02)	0.359	−0.13 (−0.06, 0.02)	0.372	−0.13 (−0.06, 0.03)	0.379
Occasional visit to park	0.31 (0.01, 0.03)	0.006	0.31 (0.01, 0.03)	0.006	0.32 (0.01, 0.04)	0.007	0.31 (0.01, 0.04)	0.01	0.32 (0, 0.04)	0.019
21–29 years	−0.19 (−0.07, 0.01)	0.088	−0.2 (−0.07, 0)	0.08	−0.23 (−0.08, 0)	0.078	−0.24 (−0.08, 0.01)	0.082	−0.24 (−0.08, 0.01)	0.089
1–2 h	0.21 (0, 0.04)	0.073	0.16 (−0.01, 0.04)	0.237	0.17 (−0.01, 0.04)	0.221	0.17 (−0.01, 0.04)	0.221	0.17 (−0.01, 0.05)	0.226

patterns, respectively. The residents viewed vegetation coverage, public activity spaces, and management as the most important factors that should be considered in the selection of future residential green spaces (**Figure 4**). The proportions of residents highly concerned with vegetation coverage, public activity spaces, and management were highest, reaching 46.45, 44.29, and 39.73%, respectively. Moreover, those concerned about water facilities, landscape patterns, basic facilities, and plant collocation were 34.62, 33.78, 29.38, and 28.76%, respectively. The basic facilities in residential green spaces include ornamental, artistic, functional, or other equipment for services.

The total level of CES was significantly affected by both the objective and subjective physical environments of the residential green spaces (**Table 4**). The results from a univariate linear regression showed that the vegetation coverage, management level, number of public activity spaces, and settings of water bodies in residential green spaces were significantly correlated with CES. The proportion of residents who were satisfied with the physical environment, including plant decoration, the coverage of green spaces, the water bodies for public activities, and the landscape patterns of residential green spaces, was significantly correlated with almost all types of CES.

The real vegetation coverage and the proportion of residents who were satisfied with plant decorations and landscape patterns were the only physical environment variables to emerge as significant in the multivariate analysis (**Table 5**), and their association with the total level of CES was examined after progressive adjustment for different blocks of variables. The proportion of residents who were satisfied with the coverage of green space was removed in the final model; we supposed it could be attributed to the multicollinearity between landscape pattern, plant decoration, and coverage of green spaces. However, the relationship between objective physical environment variables and CES attenuated after adjustment for other variables, indicating that CES was mainly influenced by residents' subjective perception of the physical environment. In addition, the percentage of residents occasionally visiting parks outside the residential areas was also significantly correlated with the level of CES.

DISCUSSION

Cultural Ecosystem Services Satisfaction Levels in the Residential Green Spaces

Although some studies have suggested that CES in residential green spaces are less valuable than those in urban green spaces, many researchers have stated that the inherent cultural value does not determine the use frequency of residents and that the distance to green spaces is closely related to individual interests (6, 10, 24, 34, 48, 49). Therefore, evaluating CES will further enrich the study of urban ecosystem services.

We defined the satisfaction level with CES <4 as low, 4–7 as medium, and >7 as high. The total satisfaction level with CES in the residential green spaces in Zhengzhou was medium (6.71), whereas residents' satisfaction with different types of CES varied. Satisfaction with the recreational services obtained the lowest

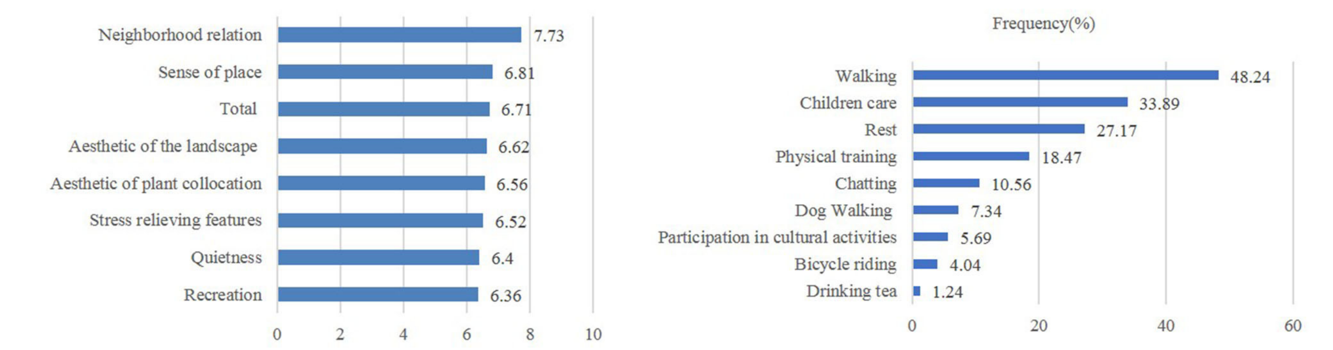

FIGURE 2 | Residents' satisfaction score on cultural ecosystem services (CES) and the main recreational activities in the residential green spaces.

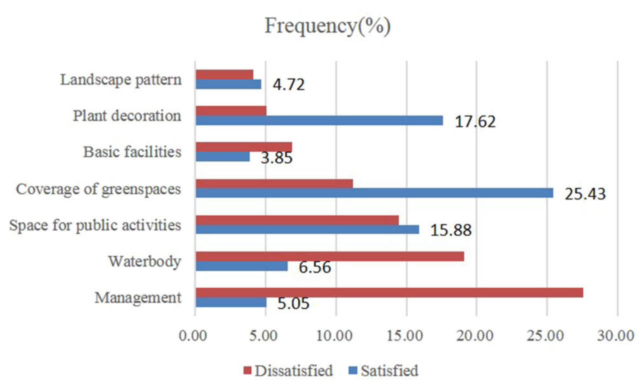

FIGURE 3 | Proportion of respondents who are satisfied and dissatisfied with the quality of residential green spaces.

score, which can be attributed to the absence of public activity spaces and facilities in most residential green spaces. Satisfaction with the overall landscape aesthetics of residential green spaces and plant collocation was relatively high, signifying the good aesthetic service level in residential green spaces in Zhengzhou. The level of spiritual services was complicated. Satisfaction with neighborhood relations and sense of belonging was the highest, whereas satisfaction with stress-relieving features and quietness was lower than the previous two factors.

Unlike previous studies, our study evaluated CES by examining residents' satisfaction, which was lowest for recreational services and highest for sense of place and neighborhood relations (**Figure 2**). Previous studies have highlighted that recreational services in urban green spaces have the highest value among all relevant factors (10, 50), whereas other studies have discovered that aesthetic features are most important (13, 14, 51). In this study, residents' satisfaction with the different CES in residential green spaces was analyzed to evaluate the supply capacity of CES. Gaps between the supply and demand of CES mostly account for the significant difference between our results and other research. However, identification of CES is mainly based on the subjective perception of residents, which produces great variability. Cultural background, customs, social status, and other socioeconomic factors influence people's perception of CES. In addition, the type of green space involved in different research also has an effect.

Multiple CES originate from the natural attributes of urban green spaces. Significantly positive correlations have commonly been observed among the different types of CES (9, 10, 13, 52). However, other studies have also discovered significantly negative correlations (14). Respondents might find it difficult to distinguish between the different types of CES, indicating that various types of CES are concentrated in a specific space (13, 53). This finding implies internal correlation and inseparable natural attributes of the various types of CES and further proves the binding effect of different CES, which might be related to the fact that the different types of CES derive from the natural attributes of the ecosystem (i.e., the surrounding natural environment).

In dense urban regions, CES provided by residential green spaces can stimulate the residents' positive attitude toward neighborhood relations, which could compensate for environmental inequality in the urban area that is, the insufficiency of other popular or large green spaces. Urban parks and woods are the most important among the different types of green spaces (10), providing high social, economic, environmental, and ecological services and values. However, the spatial distribution of these green spaces varies widely in urban areas, thereby contributing to widespread environmental inequities. The relationship between CES and residents' visit frequency to parks outside their communities in our study demonstrated that residential green spaces can effectively compensate for the lack of nearby parks owing to their proximity to residents' living areas. Therefore, the construction, investment, planning, and design of residential green spaces should be paid additional attention.

Socioeconomic Attributes of Cultural Ecosystem Services in Residential Green Spaces

CES in green spaces are stable and can be directly determined by the green landscape. Initially, we suppose the length of living in a community was believed to have caused polarization of residents' subjective evaluation of CES in green spaces. Residents who live in a community for a long time frequently visit residential green spaces, are more familiar with the surrounding environment than other groups, and thus make extensive subjective evaluations. Moreover, such residents are more socially integrated than residents who have been living in the community for a short time (42). However, residents may eventually become increasingly dissatisfied with the unreasonable characteristics of green spaces, resulting in low satisfaction with the different CES. Conversely, a short time of residence may easily polarize evaluation owing to the freshness of the residential environment. However, no significant correlation between residents' interest in CES and length of residence was observed in the present study, which can be attributed to the stability of the cultural service characteristics of the landscape in the residential green spaces of the 40 residential communities selected. In other words, established CES characteristics are difficult to change once the landscape is formed. Previous studies have reported that the landscapes in urban green spaces play an important role in improving the CES in an ecosystem (51, 54–57). Given this fact, reasonable and scientific planning and design of the landscape become extremely important for the future. Nassauer et al. stated that the ecologically innovative designs of metropolitan residential landscapes were conducive to the enhancement of long-term cultural sustainability (58).

Age is the main influence on satisfaction with CES in residential green spaces in this study. The proportion of residents who were 21–29 years old demonstrated significantly negative correlations with recreation, aesthetics, neighborhood relations, stress-relieving features, and sense of belonging ($p < 0.001$). This finding reveals that these young residents are the least satisfied with the different CES among the other residents of the community. This phenomenon can be attributed to the low satisfaction of this age group with the management and infrastructure of residential green spaces, which are key factors that determine residents' satisfaction with the CES in green spaces. The age group 21–29 years showed significantly negative correlations with the management and infrastructure of green spaces. Moreover, this age group was mainly composed of single individuals. Compared with married residents, single residents are less satisfied with CES and the surrounding residential environment (33, 58, 59). The respondents in the age group >50 years exhibited positive correlation with satisfaction regarding sense of belonging. Previous studies have reported that, compared with other age groups, older people possess a stronger sense of belonging (14) and aesthetic appreciation (60) of the urban environment, which can be attributed to their higher visit frequency to urban green spaces.

The low-income groups in our study demonstrated dissatisfaction with CES. The higher the proportion of residents with a 1,000–3,000 RMB income level, the lower the satisfaction with plant collocation. This result is consistent with the findings of Riechers et al., who discovered that residents with lower incomes had weaker natural cognition, cultural heritage, sense of social belongingness, and satisfaction with urban green spaces than those with higher incomes (14). Several studies have reported that low-income groups, or those with low socioeconomic status, were more frustrated than high-income individuals (28, 61), which may affect their satisfaction with the surrounding green spaces and thus causes negative impacts on their health. Moreover, studies have proven that income level is positively related to interpersonal relationships and the physiological and psychological health of residents (28). However, the present study determined that the gender and cultural level of residents had no significant impact on satisfaction with CES in residential green spaces.

Cultural Ecosystem Services and Visit Duration in Residential Green Spaces

Urban residents frequently visit residential green spaces; hence, CES in the green spaces within residential areas cannot be ignored. In this study, ∼40% of residents visited residential green spaces every day. The visit frequency of residents has been a focus of studies on CES in urban green spaces. The higher the visit frequency, the higher the CES level in the green spaces, which is because visiting green spaces is conducive to physiological and psychological health (29, 42, 62, 63). Many studies have measured the CES level in green spaces using the visit frequency of urban residents (9, 48, 53, 58, 64). This study discovered that the visit frequency of residents showed no significant effect on their satisfaction with CES. This result is consistent with other studies, in which the visit frequency of residents to urban green spaces was discovered to have no significant correlation with the CES value (10), satisfaction with green spaces (6), or people's psychological health (47). Subjective evaluation of residents' demand for CES emphasizes the attributes of green spaces, such as their type, area, distance, and landscape pattern, whereas the evaluation of CES supply is influenced not only by the physical characteristics of green spaces but also by the individual differences of residents, such as age (14), individual emotional factors (6), social group (65), and even survey research methods (6). In this study, respondents belonging to the age group 21–29 years only occasionally visit green spaces. These respondents showed the lowest satisfaction with the aesthetics of the green spaces, which explains the correlation between visit frequency and CES.

Visit time, especially of 1–2 h of duration, is important in the investigation of the satisfaction with CES in green spaces. The proportion of residents in this study staying in the residential green spaces for this duration was high, and the satisfaction of these residents with the recreational services and stress-relieving features was proportionally high. Previous study have revealed that the visit time of residents and the flow duration of cultural services in the residential green spaces last for 1–2 h (6), and we also found that the proportion of residents visiting green spaces for 1–2 h was positively correlated with the percentage of residents walking (**Table 4**). Walking was the main activity of residents staying for this duration, and this activity can greatly improve the physiological and psychological health of residents. However, many roads in residential areas have mixed purposes that include sidewalks, car lanes, facilities for bicycles and electric bicycles, and private car parking lots. In the 10 residential areas with the highest proportion of walking, six areas implement a sidewalk–car lane separated system. Although the remaining four areas adopt a sidewalk–car lane mixed system, large gardens

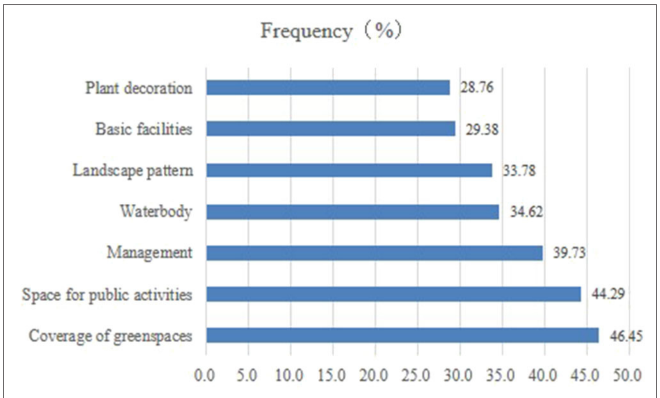

FIGURE 4 | Proportion of respondents who are concerned about the future quality of residential green spaces.

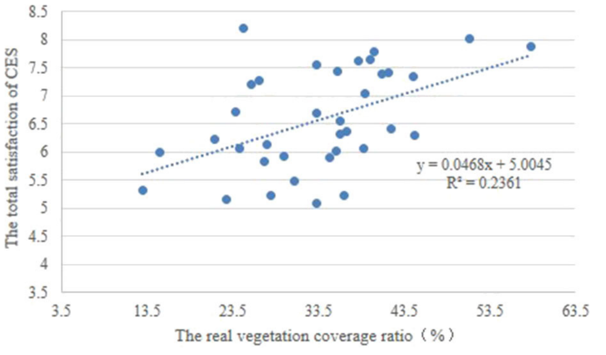

FIGURE 5 | Correlation between the total satisfaction on cultural ecosystem services (CES) and the real vegetation coverage.

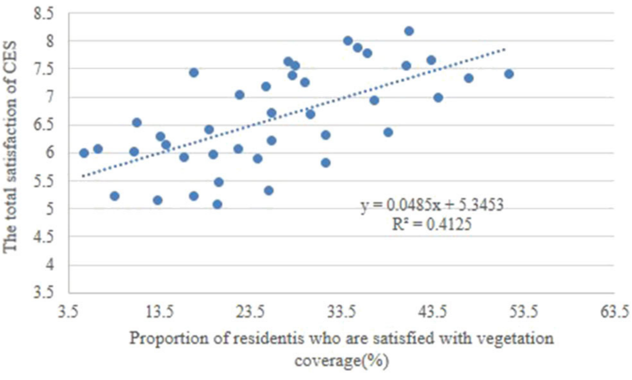

FIGURE 6 | Correlation between the total satisfaction on cultural ecosystem services (CES) and the proportion of residents who are satisfied with residential vegetation coverage.

or clustered green spaces hinder walking activities. Therefore, future planning and design of residential green spaces should create landscapes that are appropriate and safe for walking (e.g., designated sidewalks). If the green spaces in the community are limited, then public activity spaces should be enlarged to meet the residents' demands for walking activities.

Effects of Vegetation Coverage in Residential Green Spaces on Cultural Ecosystem Services

CES can be improved by increasing green coverage in residential green spaces. Increasing the area of urban green spaces can effectively optimize the biodiversity and carbon fixation of soils (66), regulate the urban microclimate, and reduce surface runoff. However, few studies have focused on the relationship between urban vegetation coverage and CES. Given similar demographic conditions, socioeconomic factors, and living conditions, residents have been found to be happier in larger surrounding green spaces and more satisfied with the surrounding environment than in smaller ones (67). The size of urban green spaces may directly influence their popularity (16). In this study, both objective and subjective green coverage were significantly related to total satisfaction with CES (**Figures 5**, **6**). This inference can explain why residents show great concern with the green coverage in residential communities (**Figure 4**). Natural vegetation is the source of CES that can increase spiritual and aesthetic services. High green coverage can provide many chances for residents to engage with nature and provide space for water bodies, in particular. In addition, public activity spaces are frequently used in residential communities to stimulate the residents' recreational activities: our study found that both the number and diversity of public activity spaces were higher in residential communities with high green coverage than in those with low green coverage.

With the increase in urban populations and the growing need for housing, urban residential areas are often dominated by high-density communities at the expense of green space. Hence, increasing CES and improving the living environment of residents in a limited green space are an important issue that must be addressed. We found that both residents' perception of plant decoration and landscape patterns in the residential green spaces could directly increase CES (**Tables 4**, **5**). Several studies have suggested that vegetation characteristics (e.g., diversity, vegetation types, abundance, color, new species, morphology, density, and configuration structure) (7, 16, 37), spatial structure, and layout of urban green spaces (6) can influence CES. The close-to-nature attribute of green spaces has been widely accepted as an effective means to improve urban green spaces (9, 16, 37). Moreover, numerous studies have proved that the quality of green spaces is extremely important in improving the physiological and psychological health of residents (47, 68). In this study, residential communities with high green coverage and large lawn areas are popular with residents owing to their accessibility and aesthetics. By contrast, dense shrub vegetation is not conducive to the improvement of green space CES owing to non-accessibility and the possibility of mosquito infestation. In Zhengzhou, half of the residential communities with high green coverage are dominated by dense shrub, which may be due to the low management cost, easy pruning, and accessible irrigation. Therefore, we recommend the cultivation of trees is economical and practical in dense urban residential areas. For communities with low green coverage, the lack of CES can be compensated for by increasing the public activity spaces.

Perception of Infrastructure and Management as the Key Influencing Factors of Cultural Ecosystem Services in Green Spaces

Infrastructure in residential green spaces includes public activity spaces (e.g., small squares, gardens, and pavilions), water facilities (e.g., fountains, pools, and artificial lakes), recreation facilities (e.g., fitness and integrated playground equipment), and artistic decorations (e.g., sculptures, chairs, streetlights, and other indicators). The results of this study suggest that satisfaction with the infrastructure in residential green spaces exhibits a significant positive correlation with the overall satisfaction with CES (**Figure 7**). The positive effects of infrastructure and the convenience of urban green spaces in improving satisfaction with CES have been established by several research studies (10, 13, 34, 59, 69). Furthermore, public activity spaces in residential areas, especially green spaces in squares and gardens, can improve satisfaction with CES. These spaces were the second most important consideration of residents when selecting communities to live in, next to green spaces coverage. Moreover, the water facilities in residential green spaces, which is the fourth most important resident concern, can improve satisfaction with CES in green spaces (**Figure 4**). Many studies have established the crucial role of wetlands (artificial or natural) in urban green spaces in improving CES (35, 49, 70–72). Plieninger observed that urban residents in Eastern Germany frequently visit water bodies (13) and often give a high evaluation (51). In summary, urban residents highly prefer wetland and water bodies. However, the water facilities in many communities in Zhengzhou are wasted or improperly managed. Therefore, residential green spaces should receive efforts to strengthen the layout and management of water landscapes and water facilities in the future.

Management of residential green spaces could improve CES greatly in residential green spaces (**Figure 7**). Many studies have proved that satisfaction with urban residential spaces is closely related to a graceful visual landscape (34, 37). However, the management of green spaces, such as irrigation, clipping, cleaning, and tidying, can directly influence the aesthetic characteristics of green spaces. These characteristics (**Figure 8**) include (1) cleanliness, which is the top concern of residents (9) and can directly influence the satisfaction with the residential environment (59); (2) standardization, which involves preventing the use of green spaces for other purposes, such as hanging out clothes and providing parking lots for bicycles, electric bicycles, and even motor vehicles; and (3) uneven heights of vegetation, drought events, and weed spreading, which may be present in residential green spaces owing to inadequate daily management (e.g., lack of clipping, irrigating, and weeding). Management was the third concern of residents in residential green spaces (**Figure 4**): therefore, additional attention and effort should be dedicated to performing regular high-quality maintenance and management of residential green spaces in the future.

Limitations

Our study has several major limitations. This study only selected five types of CES, namely, leisure and entertainment services, spiritual services, aesthetic services, sense of belonging, and social relations. Other CES (e.g., landscape identity, education, history, religion, and heritage values), which are popularly involved in other research, were not included in our study. The main reason for this exclusion was that the residential areas selected in this study were built only after 2000. We hypothesized that the values of cultural heritage, education, history, and religion would be relatively weak. All 40 residential areas are located in the populated areas of Zhengzhou, which are mainly characterized by dense buildings, as determined by the socioeconomic status levels of developing countries. Future studies should explore the influences of spatial infrastructure arrangements in green spaces on CES, including vegetation type, quantity and area of public activity spaces, type and amount of infrastructure, form and area of water landscapes, and other objective factors. Moreover, landscape and species composition and structure (landscape and vegetation) should also be investigated because such factors could influence residents' contribution to CES in the residential green spaces. The answers to these issues could provide direct scientific references for the landscape planning and design of residential green spaces. Moreover, we chose 40 residential areas within neighboring cells to ensure a sufficient sample size (number of families > 600) and minimize the impact of the surrounding environment on the CES satisfaction of residential green spaces. However, these residential areas include high-rise buildings (>18 floors), mid-rise buildings (7–18 floors), and low-rise buildings (4–6 floors) and are characterized by various types and styles of buildings. These conditions may have affected residents' direct perception and satisfaction with green space landscapes. We suggest that future research focuses on residential areas with consistent socioeconomic levels, including housing prices, architectural styles, green space coverage, management levels, geographical locations, and surrounding green space distribution, to explore the rational arrangement of the green space landscape pattern in a limited space. Such selection will further improve the green space ecosystem services and human well-being and provide a direct theoretical basis for the spatial planning and design of urban green space landscapes.

CONCLUSIONS

Exploring CES in residential green spaces could greatly enrich urban ecosystem services research. The most important research is to clarify the relationship between ecosystem services and human well-being. In this study, we found that walking, childcare, and resting were the most common recreational activities of residents. The results of the analysis show that satisfaction with recreational services in the residential green spaces was the lowest (6.26, 1–10), which can be attributed to the absence of public activity spaces. In contrast, satisfaction with neighborhood relations and the sense of place was the highest at 7.73 and 6.81, respectively, followed by aesthetic services (6.59), indicating that the spiritual and aesthetic services in the residential green spaces are excellent. Age and income

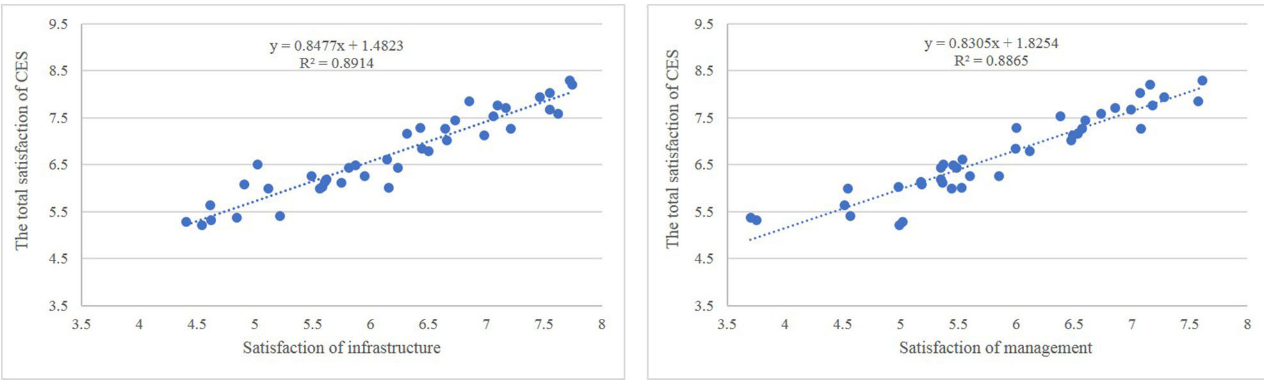

FIGURE 7 | Correlation between the satisfaction on cultural ecosystem services (CES) and satisfaction on management and infrastructure.

FIGURE 8 | Differences in the management level between the residential communities with the lowest (above) and highest (below) satisfaction on the cultural ecosystem services (CES) in green spaces.

status can influence residents' satisfaction with CES: young individuals (21–29 years old) expressed the lowest satisfaction with residential green spaces than did other groups, which might be influenced by their single status and their low satisfaction with the infrastructure in the residential environment.

Satisfaction with CES significantly increased with vegetation coverage, indicating that green vegetation is a source of high CES satisfaction. Compared with other factors, high green coverage is mostly preferred by residents. In addition, public activity spaces, management, infrastructure, and water landscapes are the other key influencing factors of CES satisfaction. Therefore, to maximize CES in residential green spaces, we suggest that public activity spaces should be increased and the daily management of residential areas should be improved when green coverage is limited. Moreover, basic facilities, particularly water landscapes, should be encouraged during the planning and design of residential green spaces. These steps are more effective and realistic in improving the CES of green spaces within areas of dense building density than increasing green space areas.

We suggest that the subjective indicators perceived by residents contribute more to CES than the objective physical environment of residential green spaces. The main reason is that CES refers to human well-being provided by green spaces, which implies residents' demand for green spaces. Future research on the relationship between green spaces' characteristics and CES should consider the physical environment (e.g., biodiversity, green space coverage, species matching, and landscape characteristics) preferred by residents, especially the gaps between the actual and the preferred characteristics favored by residents. For example, understanding the socioeconomic attributes of CES could clarify the demand characteristics of different social groups for urban green space. We suggest future research should pay more attention to different social groups' diverse demands of CES, for example, the use characteristics of the different types of urban green spaces and the diverse landscapes of the same green type. Such consideration will help ameliorate the existing planning and management of urban green spaces, maximize CES, and then protect human health. We suggest the future evaluation of urban green spaces should combine the residents' perception of demand and supply of CES, clarify the gap and trade-off between them, and then determine the key elements that affect the demand of residents, which is the fundamental purpose of urban ecosystem service research. We suggest that the answers to the above research questions will help provide constructive suggestions for building a multifunctional urban green space landscape, which is a path to urban environmental equality and a sustainable urban landscape.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be available from the corresponding author upon reasonable request.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00226/full#supplementary-material

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Seniors' Physical Activity in Neighborhood Parks and Park Design Characteristics

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Physical activity brings multiple health benefits to seniors. Neighborhood parks provide seniors with accessible spaces and opportunities to engage in physical activity. This study investigated the associations between neighborhood park design characteristics and seniors' total walking step and energy expenditure during the park visit. Seniors' total step was measured by pedometer, and energy expenditure was calculated based on self-reported activities in the park. The study was conducted in 15 neighborhood parks with an area <10 ha, and included 234 senior participants. One-way ANOVA analyses indicated that seniors in parks with larger surface area, longer trail, larger natural area and outdoor fitness equipment had taken more steps. While seniors in parks without water expended more energy. For instance, seniors in parks with surface areas <3 ha walked 507 fewer steps than seniors in parks with areas between 3 and 5 ha, and 691 fewer steps than those in parks larger than 5 ha. When including seniors' demographic attributes, multiple regression analyses suggested that total step was negatively associated with age, but positively associated with total natural area in the park and the presence of outdoor fitness equipment. Seniors energy expenditure was positively associated with BMI and the presence of outdoor fitness equipment. Energy expenditure was also related to income. These findings provide direct implications for neighborhood park design and management. Planners and designers can include more natural areas over paved areas, create longer trails and place more outdoor fitness equipment in parks to encourage seniors to walk and spend more energy.

Keywords: neighborhood park, design characteristic, senior, walking, energy expenditure, pedometer

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INTRODUCTION

Physical inactivity increases the risk of various chronic diseases, e.g., diabetes, cerebrovascular diseases, and obesity, which represent leading causes of death in the senior population. Conversely, appropriate levels of activity provide multiple benefits to seniors' physical and mental health (1, 2). Despite these facts, it is challenging to encourage seniors to stay physically active. Providing a safe, barrier-free, and healthy built environment for activities is critical to encouraging seniors' physical activity.

Urban parks are outdoor environments that facilitate physical activity for all ages (3–6), and they are also where seniors usually choose to engage in physical activity (7). Seniors prefer natural environments than built environments more than other adults (8, 9). Seniors tend to be physically active during park visits, and spend half their time walking (10). Existing research indicates that seniors prefer neighborhood park without nuisance, with many trees and plants (11). However, the characteristics of seniors' physical activity in urban parks have not been thoroughly explored, and their needs in the urban park are not well understood (4, 12–14).

Existing research has examined the relationship between parks and physical activity from two directions. The first is how park characteristics relate to residents' overall physical activity at the neighborhood level, such as the amount of moderate and vigorous physical activity of residents in 1 week (3), and whether residents achieve recommended levels of activity (15). Important park characteristics that encourage physical activity at the neighborhood level are: more parks and green space (16), larger park size (6), more features in the park (17), and proximity of residents to parks (3, 4). These findings support the inclusion of more green space and park facilities in community planning and policy-making. The second perspective is how different park activity zones encourage moderate and vigorous physical activity at the activity zone level, such as the numbers of individuals engaging in moderate and vigorous activities on park pathways or in open spaces (18). Trails have the strongest relationship with park use for walking and other physical activities (17, 19, 20). However, considering activity at the zone level does not allow researchers to capture an individual's total physical activity in the park. It is important to understand how park characteristics may influence physical activity at the level of individual visitors. Without this information, urban designers and green space managers lack key guidance on how to design a neighborhood park to maximize its health benefits.

Another potential limitation of existing studies is the methods by which physical activity is captured. Widely-used methods include self-reported activity and on-site observation. The self-reported approach asks participants to record their physical activity during a period, such as whether they visited the park for physical activity and which specific park facilities they used (17), and the duration of physical activity (21–23). However, these methods are susceptible to recall bias and may not accurately represent actual activity levels (5, 24). On-site observation tools, such as the System for Observing Play and Recreation in Communities (SOPARC), can be used to examine differences in physical activity level between various park activity zones (25, 26). Using this tool, researchers scan the whole activity zone at sampling moments and count the numbers of visitors engaging in physical activities with different intensities. However, scanning may not be effective in heavily-used urban parks full of people, and accurate recording is often costly and time-consuming (5). Therefore, objective approaches that can efficiently collect data on park users' physical activity are needed (5, 21). Equipment such as pedometers and accelerometers have been used to measure the intensity of physical activity (5, 27, 28), but few studies have employed them to examine physical activity in urban parks.

Furthermore, few studies have addressed how park characteristics may impact physical activity from a design perspective (29). Designers are interested in knowing how many paved open spaces should be provided, how the trails should be distributed, and how large natural areas such as lawns and groves should be. However, existing findings may only suggest the presence of trail that would facilitate physical activity, rather than addressing design characteristics of these features, thus may have limited implications for park design. Therefore studies that can bear design implications and inform design practices are needed (5, 26, 30, 31).

This study aims to address the above-mentioned knowledge gaps by examining how neighborhood park design characteristics relate to seniors' walking and energy expenditure on park visit at the individual level. We used pedometers to measure seniors' total steps taken during their park visits and estimated energy expenditure based on their recall of the activities they engaged in. This study can provide empirical evidence on how neighborhood park design attributes may relate to the physical activity of seniors in parks as well as providing an approach for collecting physical activity data. Moreover, the research findings can inform future urban park design and management to promote physical activity in seniors.

METHODS

Study Sites

Neighborhood parks provide seniors with accessible outdoor spaces to engage in physical activities. Fifteen neighborhood parks in the city of Shanghai were selected as study sites (**Table 1**, **Figure 1**). Shanghai is the second-largest city in China, with an area of ~6,300 km^2 and a population of 24 million people at the end of 2016 (33). Its population density is very high, with 18,000 to 32,000 residents per km^2 in the central districts (33). Three main ring-shaped roads (the inner ring, the middle ring and the

TABLE 1 | Selected urban parks.

Area category	No.	Park name	Area (ha)	Number of visitors in 2015 (32)	District
Park area < 3 ha	1	Songhe Park	1.6	712,604	Yangpu district
	2	Liyuan Park	1.7	323,092	Huangpu district
	3	Huaihai Park	2.5	1,942,450	Huangpu district
3 ha ≤ Park area < 5 ha	4	Penglai Park	3.2	186,016	Huangpu district
	5	Minxing Park	3.2	834,982	Yangpu district
	6	Guilin Park	3.6	242,040	Xvhui district
	7	Caoxi Park	3.8	624,430	Xvhui district
	8	Siping Technology Park	3.8	398,122	Yangpu district
	9	Douxiang Park	3.8	291,363	Pudong new district
	10	Jiangpu Park	3.8	1,228,734	Yangpu district
	11	Sichuan North Road Park	4.5	10,723,216	Hongko district
5 ha ≤ Park area < 10 ha	12	Quyang Park	6.2	1,468,108	Hongko district
	13	Fuxing Park	6.5	7,515,059	Huangpu district
	14	Nan Park	8.6	1,012,700	Huangpu district
	15	Xvjiahui Park	8.9	12,157,350	Xvhui district

outer ring) divide Shanghai into four parts, and the 6th National Census of Population shows that population density decreases from the area within the inner ring to the area beyond the outer ring (34). The city has 165 urban parks with a total area of 24 km^2 (32). Due to limited land availability, most urban parks in Shanghai have a small surface area (35); around half of them are <5 ha (36). Fifteen neighborhood parks with surface areas of between 3 ha and 10 ha were selected as study sites based on the following criteria: 1. the park administrators approved data collection; 2. detailed digital survey documents of the park were obtainable; and 3. the park served the general public and was open to all. The 15 neighborhood parks all have common activity zones, such as lawns, trails, and paved open spaces (**Figure 2**). All parks are either within or very close to the middle ring and are frequently used by the citizens. Annual visitor numbers from 2015 for the selected parks ranged from 186,016 to 12,157,350.

Procedure

The study was conducted on sunny or cloudy weekdays during 3 weeks in October of 2017, when the weather in Shanghai is conducive to outdoor activities. Sampling days consisted of two data collection sessions, one in the morning (9:00 am−12:00 pm) and one in the afternoon (1:00 pm−5:00 pm). Researchers were stationed at the most frequently-used park entrance and invited seniors entering the park to voluntarily participate in the study. Three criteria were used in screening participants: 1. The participant should be aged 60 and above, 2. The participant did not need walking aids, and 3. The participant planned to visit the park, rather than pass through. Once a senior park user agreed to participate in the study, he or she was asked to sign a consent form and provided with the researcher's telephone number. The participant's telephone number was also recorded with their approval.

When distributing pedometers, the researcher turned on the pedometer and made sure it had been reset, and helped the participant put it around their neck or on their waist, where pedometer has a high reliability (37). We also instructed the participant not to touch the buttons on pedometers to prevent them from turning it off or resetting the record by accident. When pedometers were returned, the researcher recorded the total steps measured, as well as the time of return

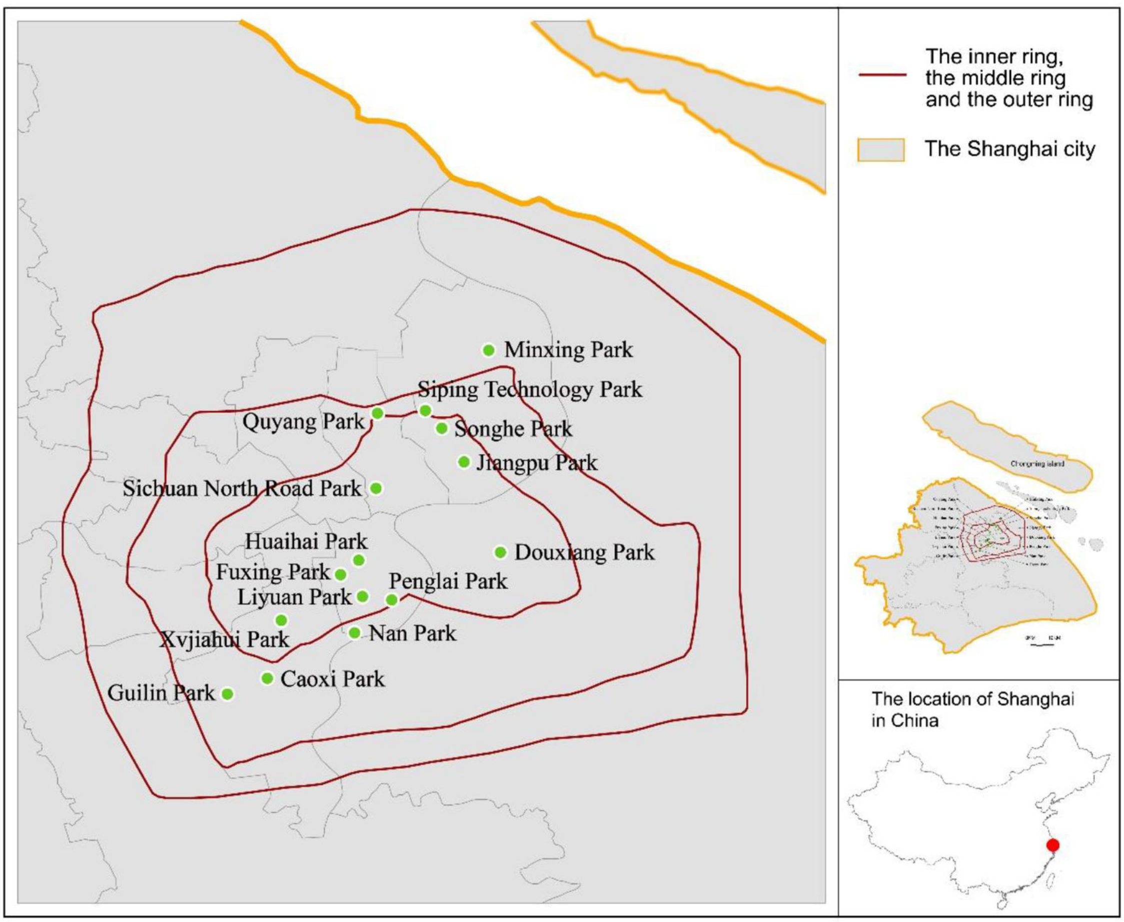

FIGURE 1 | Locations of the 15 neighborhood parks in Shanghai.

FIGURE 2 | Master Plans of the 15 neighborhood parks. [Figure credit: authors; an adapted version of figure has been published in article that belong to the same project (13).]

in order to discriminate step data from different participants. At the time of return, participants were invited to complete a questionnaire addressing their demographic information, daily park use patterns, and physical activities in the park. We asked participants to recall and report in chronological order each activity they engaged in and the duration of each activity.

Measures

Total Steps and Energy Expenditure in Parks

The physical activity of senior park users was assessed using the total steps measured by pedometer and by self-reported energy expenditure. The pedometer used in this study was the Yamax Power Walker EX-510 (Yamax Corp., Tokyo, Japan), which showed a high accuracy in counting steps (37). Existing research has proven the validity of pedometer in measuring physical activity (27, 28). In particular, the Yamax pedometer has been shown to be very accurate in recording steps and distance (38), and in counting the steps of seniors who neither uses walking aids nor walk very slow (39). Specifically, when walking speed is >0.83 m/s, its step counts have acceptable error rates (40). Typically, seniors aged 60 and above have a walking speed >1 m/s (41), thus it is appropriate to measure their steps with a pedometer.

Energy expenditure was calculated based on participants' reported activity types and durations. Using the Compendium for Physical Activities, we identified the metabolic equivalent (MET) intensity level for each type of activity reported by participants. The MET is a standardized measure of activity intensity defined as the ratio of work to resting metabolic rate. For example, walking is estimated as 3 METs and running is considered to be 6 METs. We calculated the energy expenditure of each participant for each activity by multiplying their weight (kg), the energy cost (METs) of a given physical activity ($kcal \cdot kg^{-1} \cdot h^{-1}$), and the duration of the physical activity (h).

Park Design Characteristics

We measured seven park design characteristics: 1. Park area, 2. Total trail length, 3. Total paved activity zone area, 4. Total natural area, 5. Presence of water, 6. Presence of outdoor fitness equipment, and 7. Presence of court (**Figure 3**). **Table 2** provides the definition, justification, type, and data source for these design characteristics. We hypothesized that parks

FIGURE 3 | Park scenes of the study parks.

with larger areas, more trails, larger paved activity zone area, larger natural area, water features, outdoor fitness equipment, and courts would be associated with more steps and more energy expenditure for senior users. All design variables were measured based on surveys of parks in AutoCAD format provided by the Shanghai Greening Administration Bureau and local park administrators. The researchers visited all 15 parks, field-validated the survey drawings, corrected errors, identified activity zone types, and then calculated values for each park's design characteristic variables using AutoCAD (**Figure 4**).

Statistical Analyses

Statistical Analyses were conducted using IBM SPSS Statistics. Descriptive statistics were used to determine general characteristics of the collected sample data and park design characteristics. One-way ANOVA tests were then fitted to test whether seniors' physical activity, including total steps and energy expenditure, differed between parks with different design characteristics. In ANOVA analysis, park design characteristics were coded as categorical variables (**Table 2**). Park area was classified as smaller than 3 ha, 3–5 ha, and larger than 5 ha; trail length as <1 km, 1–2 km, and longer than 2 km; paved activity zone areas as <0.4 ha, 0.4–0.6 ha, and larger than 0.6 ha; and natural area as <2 ha, 2–4 ha, and larger than 4 ha.

We then used regression models to examine the relationships between park design characteristics and seniors' walking step and energy expenditure. In the analyses, variables of park area, total trail length, total paved activity zone area and total natural area were coded as continuous variables, other park design variables, including presence of water, presence of outdoor fitness equipment, and presence of court were coded as categorical variables. First, we examined whether our data demonstrated a multi-level structure (i.e., park participants nested within parks). If so, mixed models would be required for analysis. However, when we calculated the intra-class correlation coefficient, we found the between-cluster variance to be very small (ICC = 0.050 for total steps and ICC = 0.038 for energy expenditure); this ruled out any need for a mixed model. We fitted linear regression models to predict total steps and energy expenditure using park design characteristics and included seniors' demographic attributes as control variables. Total steps and energy expenditure were log-transformed, as they displayed right-skewed distributions. Since park design characteristic variables exhibited collinearity, stepwise models selection were applied for the both models.

RESULTS

Descriptive Statistics

Total of 257 senior park users participated in the study (**Table 3**). Those who returned with the pedometer turned

TABLE 2 | Seniors' physical activity variables and neighborhood park design variables.

		Definition/measurement	Justification	Variable type	Data source
Seniors' physical activity variables					
	1. Total step	Total steps seniors walked during the park visit	–	Continuous	Pedometer
	2. Energy expenditure	Total energy senior expended during the park visit	–	Continuous	Questionnaire/ calculated based on compendium of Physical Activities
Neighborhood park design variables					
	1. Park area	Surface area of the entire park	Large parks tend to have more features (42), which may encourage more physical activities.	Categorical (< 3 ha, 3–5 ha and ≥5 ha)/Continuous	Park AutoCAD map/site visit
	2. Total trail length	Total length of all trails in the park	Parks with a track appeared to draw more seniors (4).	Categorical (<1 km, 1–2 km and ≥2 km)/Continuous	Park AutoCAD map /site visit
	3. Total paved activity zone area	The total area of all paved activity zones in the park, e.g., open space, court and paved children playground.	Larger activity zone appeared to attract more users (43).	Categorical (< 0.4 ha, 0.4–0.6 ha and, ≥0.6 ha)/Continuous	Park AutoCAD map /site visit
	4. Total natural area	Area of natural elements, e.g., water, lawn, grove.	Nature experience could benefit mental health (44, 45). Adolescents exposed to more nature have a better daily mood (46).	Categorical (< 2 ha, 2–4 ha and, ≥4 ha)/Continuous	Park AutoCAD map /site visit
	5. Presence of water	Presence of water in the park	Water contributes to a better mood (47, 48).	Categorical (0 = without, 1 = with)	Park AutoCAD map /site visit
	6. Presence of outdoor fitness equipment	Presence of fitness equipment in the park	Outdoor fitness equipment attracts a lot of senior users (49, 50) and contributes to the increase of moderate and vigorous physical activity (51).	Categorical (0 = without, 1 = with)	Park AutoCAD map /site visit
	7. Presence of Court	Presence of court in the park	Use of courts facilitates physical activity in the park (4, 18, 52)	Categorical (0 = without, 1 = with)	Park AutoCAD map /site visit

off, or whose survey results were inconsistent with activity durations recorded on the pedometer, were excluded from the study. A total of 234 (91.05%) participants had valid pedometer data and demographic information and were included in the analysis. On average, each park had 16 valid senior participants (*Min* = 11, *Max* = 23, *SD* = 3.54). As indicated in **Table 3**, the average age of participants was around 70 years old (*Min* = 60, *Max* = 93, *SD* = 7.54) and the average BMI of participants was 23.45 (*Min* = 12.37, *Max* = 31.25, *SD* = 2.89). One hundred and thirty-two (56.4%) participants were male, 188 (80.3%) lived with their spouse, and 112 (47.9%) had a household monthly income between 5,000 and 10,000 CNY (749-1498 USD). Eighty-six (36.8%) seniors reported that their health was excellent or good, and 132 (56.4%) seniors felt their health was fair. One hundred and sixty-seven (71.4%) participants claimed that they came to the park for exercise, and 51 (21.8%) said they came with multiple purposes.

Out of all 234 participants with valid data, 191 recalled the types of physical activity they engaged in and the duration of each type of physical activity. On average, each participant walked 2,278 steps in the park (*Min* = 158, *Max* = 10,320, *SD* = 1,642.403). Of these 191 participants, one (0.52%) engaged in four types of physical activities; 11 (5.76%) engaged in three kinds of physical activities; 82 (42.93%) took parts in two kinds of physical activities; and 97 (50.79%) participated in only one type of physical activity. In total, participants reported 27 types of physical activities, the most frequently mentioned of which were walking (139 seniors, 72.77%), meeting and chatting with friends (29 seniors, 15.18%), and using outdoor fitness equipment (20 seniors, 10.47%). We calculated the energy expenditure of each participant for each activity by multiplying their weight (kg), the energy cost of a given physical activity ($kcal\cdot kg^{-1}\cdot h^{-1}$), and the duration of the physical activity (h^{-1}). The total energy expenditure of a participant was then calculated as the sum of energy expenditures across all kinds of activities they performed.

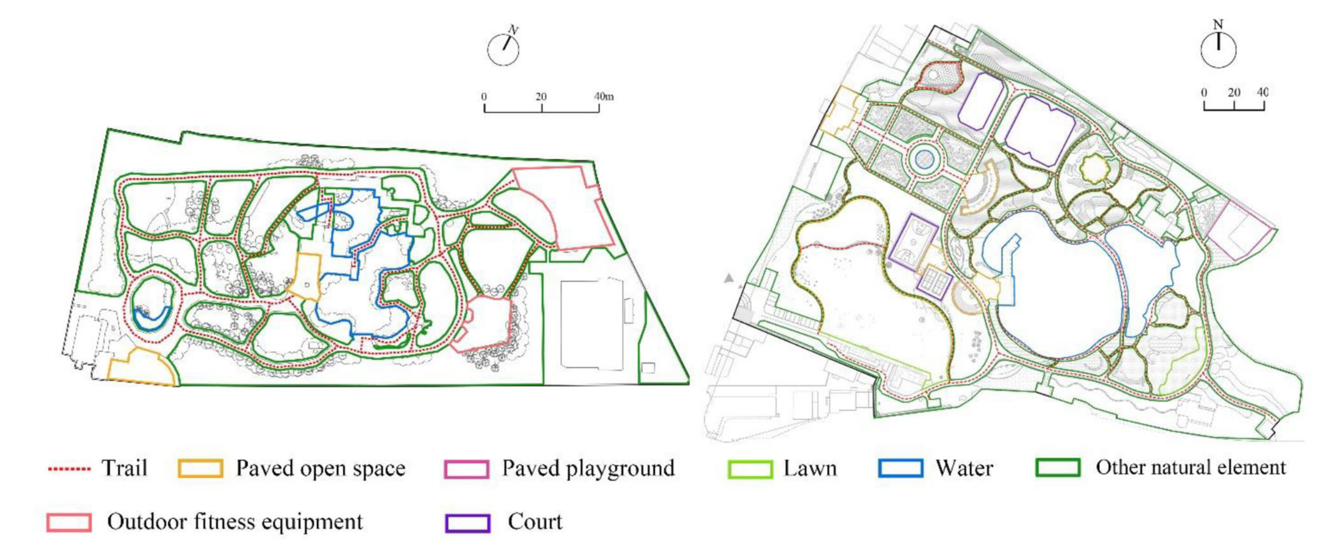

FIGURE 4 | Park activity zone type identification of Songhe Park (left) and Quyang Park (right).

TABLE 3 | Descriptive statistics for senior participants.

		Minimum	Maximum	Mean	Std. deviation
1. Age		60.00	93.00	69.52	7.540
2. Height (m)		1.48	1.84	1.64	0.075
3. Weight (km)		30.50	90.00	63.54	9.859
4. BMI		12.37	31.25	23.45	2.894
			Frequency	Percent	
5.Gender	Male		132	56.4	
	Female		102	43.6	
6. Marital status	Single		46	19.7	
	Not single		188	80.3	
7. Houshold monthly income (CNY)	<3,000		31	13.2	
	3,000–5,000		65	27.8	
	5,000–10,000		112	47.9	
	10,000–20,000		26	11.1	
8. Self-reported health condition	Excellent		38	16.2	
	Good		48	20.5	
	Fair		132	56.4	
	Bad		16	6.8	
9.Park visit purpose	Exercise		167	71.4	
	Contact with nature		14	6.0	
	Meet friends		2	0.9	
	Multiple		51	21.8	

On average, each senior expended 148.27 kcal (*Min* = 14.50, *Max* = 1007.40, *SD* = 113.579) during their stay in the park.

Park Design Characteristics

Table 4 reports descriptive statistics for park design characteristics. On average, the 15 neighborhood parks had a surface area of 4.4 ha (*Min* = 1.61, *Max* = 8.92, *SD* = 2.219), a total trail length of 2.27 km (*Min* = 0.533, *Max* = 6.05, *SD* = 1.339), a total paved activity area of 0.49 ha (*Min* = 0.12, *Max* = 0.86, *SD* = 0.204), and a total natural area of 2.68 ha (*Min* = 0.96, *Max* = 5.00, *SD* = 1.218). Twelve parks (80%) had water features, six parks (40%) had outdoor fitness equipment, and four parks (26.7%) contained courts. Correlation analyses were used to detect associations between park design characteristics (**Table 5**). The results indicated that park area was positively associated with trail length, r (14) = 0.888, $p < 0.001$, total paved activity zone area, r (14) = 0.660, $p < 0.005$, and total natural area, r (14) = 0.962, $p < 0.001$. Parks with larger natural area also have longer trails r (14) = 0.858, $p < 0.001$, and larger total paved activity zone area, r (14) = 0.588, $p < 0.005$. Parks with courts also tend to have larger paved activity zone area, r (14) = 0.523, $p < 0.005$.

Does Seniors' Total Step and Energy Expenditure Differ in Parks With Different Design Characteristics?

ANOVA analyses were performed to detect the differences in seniors' mean total step and mean energy expenditure in parks with different design characteristics. The results indicated that on average, seniors walk more steps in parks with larger surface area, $F_{(2, 231)} = 2.45$, $p = 0.089$, longer trail, $F_{(2, 231)} = 2.85$, $p = 0.060$, larger natural area, $F_{(2, 231)} = 6.27$, $p = 0.002$, and outdoor fitness equipment, $F_{(1, 231)} = 4.00$, $p = 0.047$ (**Table 6**, **Figure 5**). In particular, ANOVA *post hoc* (LSD) analyses indicated that senior participants in parks with <3 ha total area walked 507 fewer steps than those in parks with areas between 3 and 5 ha ($p = 0.074$), and 691 fewer steps compared to seniors in parks larger than 5 ha ($p = 0.032$) (**Table 7**). On average, seniors in parks with more than 2 km of trails walked 739 more steps ($p = 0.021$) than seniors in parks with <1 km of trails. Similarly, seniors in parks with <2 ha of natural area walked 724 fewer steps than those in parks with between 2 and 4 ha of natural area ($p = 0.003$), and 946 fewer steps ($p = 0.002$) than those in

TABLE 4 | Descriptive statistics for park design characteristics.

		N	Minimum	Maximum	Mean	Std. deviation
Park area (m^2)		15	16058.52	89172.96	44045.893	22192.869
Total trail length (m)		15	533.27	6048.12	2268.229	1339.746
Total paved activity zone area (m^2)		15	1176.88	8589.45	4925.184	2048.820
Total natural area (m^2)		15	9613.77	50033.88	26764.212	12176.843
			Frequency	**Percent**		
Presence of water	No water		12	80.0		
	With water		3	20.0		
Presence of outdoor fitness equipment	No fitness equipment		6	40.0		
	With outdoor fitness equipment		9	60.0		
Presence of court	No court		4	26.7		
	With court		11	73.3		

TABLE 5 | Correlation matrix for park design characteristic variables.

	Park area	Total trail length	Total paved activity zone area	Total natural area	Presence of water	Presence of outdoor fitness equipment
Total trail length^p	0.888**					
Total paved activity zone area^p	0.660**	0.454				
Total natural area^p	0.962**	0.858**	0.588**			
Presence of water^S	0.424	0.463	0.116	0.386		
Presence of outdoor fitness equipment^S	−0.346	−0.157	−0.409	−0.157	0.068	
Presence of Court^S	0.489	0.209	0.523**	0.384	0.302	−0.185

^{p}Pearson correlation coefficients; ^{S}Spearman correlation coefficients.
$^{**}p < 0.05$ (2-tailed).

TABLE 6 | ANOVA analysis for seniors' total step, energy expenditure and park design characteristics.

		Steps					
		Sum of squares	**df**	**Mean square**	***F***	**Sig.**	**Sum of squares**
Park area	Between groups	13055887.570	2	6527943.785	2.450	0.089*	18761.540
	Within groups	615458633.300	231	2664323.088			2432275.131
	Total	628514520.900	233				2451036.671
Total trail length	Between groups	15140996.130	2	7570498.067	2.851	0.060*	28385.552
	Within groups	613373524.800	231	2655296.644			2422651.119
	Total	628514520.900	233				2451036.671
Total paved activity zone	Between groups	4417467.558	2	2208733.779	0.818	0.443	19517.993
	Within groups	624097053.300	231	2701718.846			2431518.678
	Total	628514520.900	233				2451036.671
Total natural area	Between groups	32350036.860	2	16175018.430	6.267	0.002**	3074.281
	Within groups	596164484.000	231	2580798.632			2447962.390
	Total	628514520.900	233				2451036.671
Presence of water	Between groups	30279.745	1	30279.745	0.011	0.916	70633.114
	Within groups	628484241.200	232	2708983.798			2380403.557
	Total	628514520.900	233				2451036.671
Presence of outdoor fitness equipment	Between groups	10642189.750	1	10642189.750	3.996	0.047**	13934.383
	Within groups	617872331.200	232	2663242.807			2437102.288
	Total	628514520.900	233				2451036.671
Presence of court	Between groups	3754170.004	1	3754170.004	1.394	0.239	181.134
	Within groups	624760350.900	232	2692932.547			2450855.537
	Total	628514520.900	233				2451036.671

$^{*}p < 0.10$ (2-tailed). $^{**}p < 0.05$ (2-tailed).

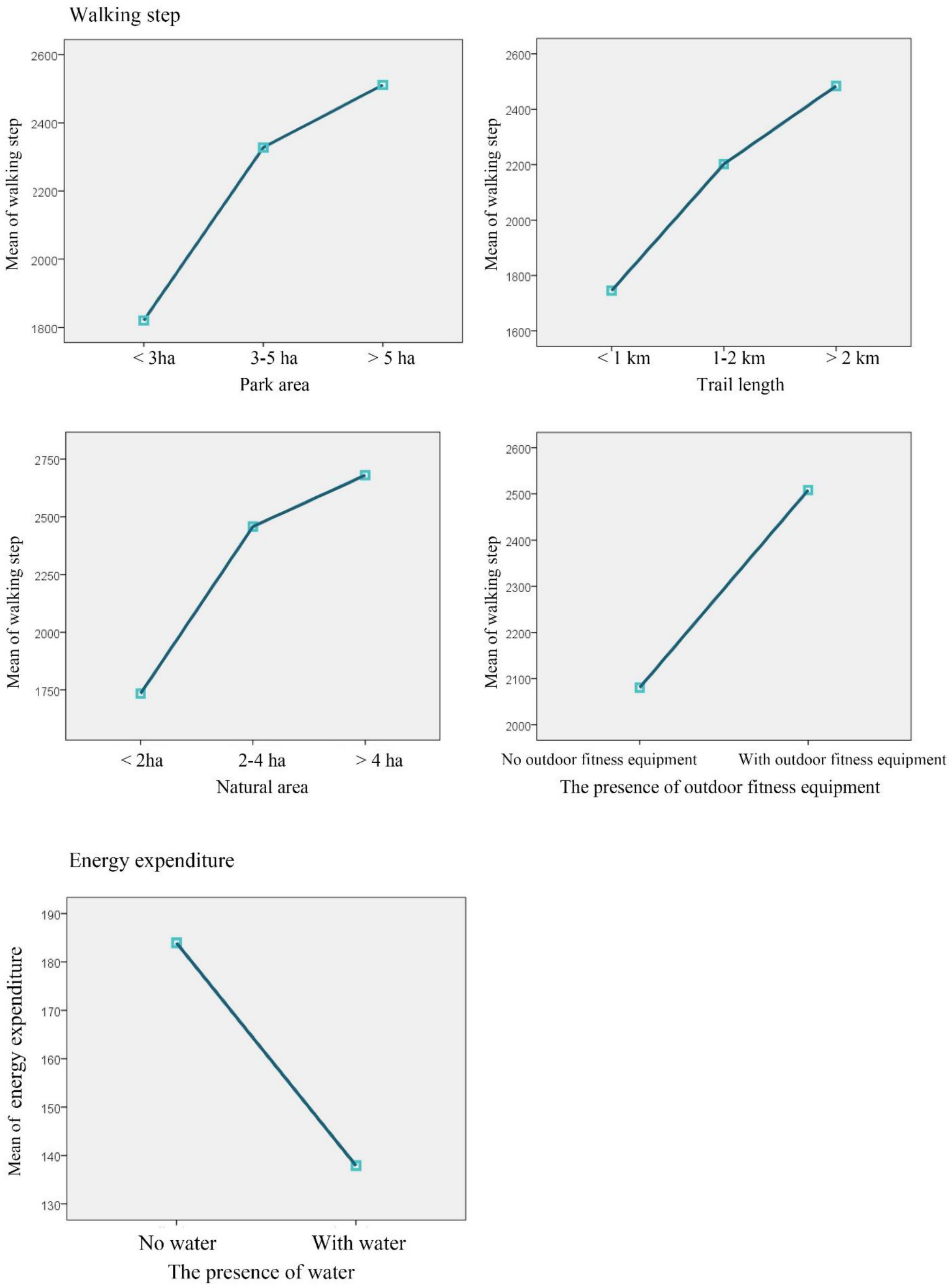

FIGURE 5 | Differences in seniors' total walking step and energy expenditure in parks with different design characteristics.

parks with more than 4 ha of natural area. Seniors expended more energy in parks without water, $F_{(1,189)} = 5.608$, $p = 0.019$, but no significant differences in seniors' average energy expenditure were detected between parks with different sizes, $F_{(2,188)} =.725$, $p = 0.486$, trail lengths, $F_{(2,188)} = 1.101$, $p = 0.335$, paved activity zone areas, $F_{(2,188)} = 0.755$, $p = 0.472$, natural areas, $F_{(2,188)}$

TABLE 7 | AOVA *post hoc* (LSD) analysis for total step and neighborhood park design characteristics.

	(I)	(J)	Mean difference (I-J)	Std. error	Sig.
Park area	< 3ha	3–5 ha	−507.255	282.882	0.074*
		≥5 ha	−690.803	320.756	0.032**
	3–5 ha	≥5 ha	−183.548	253.954	0.471
Trail length	<1 km	1–2 km	−456.819	332.383	0.171
		≥2 km	−738.972	317.174	0.021**
	1–2 km	≥2 km	−282.154	234.274	0.230
Natural area	< 2 ha	2–4 ha	−723.567	240.629	0.003**
		≥4 ha	−945.942	305.279	0.002**
	2–4 ha	≥4 ha	−222.374	281.796	0.431

* $p < 0.10$ (2-tailed). ** $p < 0.05$ (2-tailed).

$= 0.188$, $p = 0.889$, presence of outdoor fitness equipment, $F_{(1, 189)} = 1.081$, $p = 0.300$, or presence of court, $F_{(1, 189)} = 0.014$, $p = 0.906$.

Do Relationships Between Seniors' Total Step and Energy Expenditure and Neighborhood Park Design Characteristics Still Hold When Controlling for Demographic Attributes?

The relationship of park design characteristics and seniors' total steps and energy expenditures were evaluated using multiple stepwise regression analyses (**Table 8**). We included age, gender, BMI, family income, health condition, and visit purpose as control variables. The multiple stepwise regression models indicated that seniors' walking step was negatively associated with senior age ($\beta = -0.164$, $p = 0.011$), but positively associated with natural area ($\beta = 0.158$, $p = 0.015$) and the presence of outdoor fitness equipment ($\beta = 0.149$, $p = 0.021$) in the park. These three factors explained 6.4% ($p = 0.002$) of the variance in step counts in the parks. Seniors' energy expenditure was positively related to BMI ($\beta = 0.241$, $p = 0.001$), household monthly income between 5,000 and 10,000 ($\beta = 0.160$, $p = 0.024$) and the presence of outdoor fitness equipment ($\beta = 0.161$, $p = 0.024$) in the park, these three factors explained 9.9% of the variance ($p = 0.000$) in senior energy expenditure.

DISCUSSION

This study examined the relationships between neighborhood park design characteristics and seniors' total steps and energy expenditure in the park, using both objective and self-reported measures. We sampled 15 different parks to enhance the generalizability of the results.

Seniors' Age, Household Monthly Income, and Physical Activity

The results indicated that younger seniors walked more in the park, and seniors with a household monthly income between 5,000 and 10,000 have larger energy expenditure than those with a monthly income <3,000 CNY. Existing research indicates that the young elderly tend to engage in more physical activity than the old elderly in daily life (53), and our findings suggest that this difference existed in park visits. Human skeletal muscle atrophies with age (54), and seniors in the 50–59 age have a better physical function than those in the 60–69 and 70–79 age groups (55). Therefore, young seniors are expected to walk more in the park. The needs of seniors in different decades and with different physical capabilities should be considered in urban park design and management. Seniors with higher incomes are more likely to participate in health promotion programs (56), report better health (57), have lower body mass index, and engage in more moderate and vigorous physical activity (58). That might explain our findings that compared to seniors with a household monthly income <3,000 CNY, seniors with a household monthly income between 5,000 and 10,000 CNY expend more energy in the park. On the other hand, urban park provides free settings for seniors with low income to engage in physical activity, efforts are needed to encourage those seniors to actively use urban parks.

Park Size, Natural Area, and Seniors' Walking

Our findings suggest that seniors in larger neighborhood parks walk more. However, existing research with adults indicates that park size is not associated with the chance whether a park is used for physical activity (17), and features rather than park size is more important for park-based physical activity (4). One possible explanation is that previous studies used binary measures of physical activity, while our study measured walking steps and energy expenditure using continuous variables, which allows for quantitative comparisons between parks. More time spent in a park has been shown to correlate with higher levels of physical activity (59). Larger parks provide more area to explore and may encourage seniors to stay and walk for longer periods. We also found that larger natural area was associated with more walking steps. The health benefits of walking in natural areas have long been recognized (60). Nature is important to seniors (61), and can help seniors release stress (62). Compared to other adults, seniors have a stronger motivation to walk in natural environment (8). Larger natural area may contribute to a better mood and attracted seniors to stay longer and walk more. The findings suggest that we can provide larger natural area to encourage seniors' walking in the park.

Trail Length and Seniors Walking

We found total trail length is related to seniors' total steps in the park. Existing research suggests that parks with tracks draw more seniors (4). A study in Missouri finds that users of a trail longer than 0.25 mile are more likely to report an increase in physical activity (63). Trail in the park is where seniors

TABLE 8 | Total step, energy expenditure, and park design characteristics and senior demographic attributes (stepwise model).

	Variables	Coef. (B)	*SE*	*St. Coef. (β)*	Sig.	VIF	Overall model
Total step							
	(Constant)	3.592	0.213		0.000		$R^2 = 0.064$ *Sig.* = 0.002
	Age	−0.008	0.003	−0.164	0.011	1.005	
	Total natural area	4.889E-6	0.000	0.158	0.015	1.017	
	Presence of outdoor fitness equipment	0.105	0.045	0.149	0.021	1.015	
Energy expenditure							
		1.465	0.162		0.000		
	BMI	0.023	0.007	0.241	0.001	1.038	
	Household monthly income between 5,000 and 10,000	0.089	0.039	0.160	0.024	1.009	$R^2 = 0.099$ *Sig.* = 0.000
	Presence of outdoor fitness equipment	0.090	0.040	0.161	0.024	1.035	

Total step and energy expenditure are log-transformed.

walking on, and longer trail can provide more opportunities for seniors to walk thus may facilitate seniors walking. In parks of limited area, designers can distribute longer trails to facilitate senior walking; further investigation is needed to explore how the characteristics of park trails may facilitate walking by seniors (64).

Outdoor Fitness Equipment and Seniors' Physical Activity

We found that the presence of outdoor fitness equipment was associated with total steps and energy expenditure of seniors. Fitness equipment can accommodate a variety of fitness goals, and their presence provides opportunities for physical activity beyond walking. Existing studies reported that outdoor fitness equipment in parks attracts senior users (49, 50), and seniors use this equipment with the primary motivation of exercising and improving health (7). Compared to other adults, seniors have less access to walking trails and indoor gyms (63). In contrast, outdoor fitness equipment can provide seniors with important exercise opportunities (50). Landscape architects can provide outdoor fitness equipment in urban parks to facilitate the physical activity of senior visitors, and how seniors use outdoor fitness equipment should be further explored.

Limitations

The present study has some limitations that should be considered. The parks included in the study were neighborhood parks with areas of <10 ha, and thus the results may not be applicable to larger parks such as city parks, regional parks or natural reserves. Although we included 15 parks to ensure the representativeness of the sites, all are located in Shanghai, China. The patterns of park features and park use may differ in less-dense urban areas, in suburban and rural locations, and in other cultures. Additionally, we used a convenient sample of seniors visiting the parks who volunteered to participate in the study. It is uncertain whether this population group displayed characteristics that may influence the physical activity data systematically. Third, only step counts were measured, and only pedometers were used for measurement. Future studies should consider combining pedometers, accelerometers, heart-rate monitors, armbands, or multi-sensor devices for more accurate estimates of activity intensity, activity duration, and energy expenditure.

CONCLUSION

This study aimed to investigate the associations between neighborhood park design characteristics and seniors' walking and energy expenditure during park visits. The results indicated that park area, total trail length, and total natural area of the park were positive predictors of more walking. The presence of outdoor fitness equipment also contributed to more walking and energy expenditure. In addition, demographic and socioeconomic factors, as well as BMI are related to seniors' activities in parks. For example, senior's total step count was negatively associated with age; and their energy expenditure was positively related to BMI. More energy was also expended by seniors with a monthly household income between 5,000 and 10,000 CNY as compared to those with a monthly household income of <3,000 CNY. These findings can be used to guide park design and management to promote walking and active recreation in parks. For instance, planners and designers can include more natural areas and less impervious areas, create longer trails, and provide more outdoor fitness equipment in parks, especially in parks that are located in communities that demonstrate greater inactivity and obesity. Park use patterns and the needs of seniors with diverse demographic attributes should also be considered and addressed in future park design and management practice.

DATA AVAILABILITY STATEMENT

The raw data can not be shared because sensitive location information is asked to be reserved by IRB.

ETHICS STATEMENT

Our study has been approved by the Institutional Review Board of Tongji University and we confirm that the patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

All authors listed have made a substantial, direct and intellectual contribution to the work, and approved it for publication.

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Does Green Space Really Matter for Residents' Obesity? A New Perspective From Baidu Street View

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Despite a growing literature on the topic, the association between neighborhood greenness and body weight is inconsistent. The objective of this research is to examine the association between neighborhood greenness and residents' obesity levels in a high population density area. We accounted for three greenness features: green access, green exposure, and view-based green index. We used the novel technique of deep convolutional neural network architecture to extract eye-level information from Baidu Street View images to capture the urban vertical greenness level. The research involved a survey with 9,524 respondents from 40 communities in Shanghai. Generally, we found all aspects of horizontal greenery, vertical greenery, and proximity of green levels to be impactful on body weight; however, only the view-based green index consistently had an adverse effect on weight and obesity.

Keywords: green space, eye-level, street view image, BMI, Shanghai

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INTRODUCTION

Scholars have found links between the built environment and health-related outcomes, including mental health (1), cardiovascular outcomes (2), and mortality (3) through a socio-ecological approach, emphasizing individual interactions with the built environment (4, 5). There has been an increasing focus on the relationship between green space and residents' body mass index (BMI), as being overweight or obese poses many health risks, including diabetes, heart disease, and certain forms of cancer. Indeed, obesity has become a global public health issue. As reported, the number of obese men and women rose from 232 to 304 million from 1975 to 2014 (6). Greenness can promote people's physical activity, which can facilitate healthy weight management (7). Thus, in general, good neighborhood greenness levels have been associated with a lower likelihood of being overweight or obese. However, the association between greenness and body weight seems less consistent than believed (2, 8–10). For instance, Cummins and Fagg (2012) found that green space was associated with increased chances of being overweight and obese, but this relationship has only been found in urban areas in 2000–2003 (11). There is no significant correlation between green space and BMI (12, 13), and the health effects of urban green spaces may vary according to gender, socioeconomic profile, and local context (14, 15).

With increasing evidence of an association between neighborhood greenness and resident weight status, some studies examining the association between eye-level neighborhood greenness and people's BMI have emerged (16, 17). The present measurements of the health effect of green space mostly rely on green exposure and access; a potential reason for such inconsistent findings is the differing approaches used to measure green space features (8). Specifically, most epidemiologic studies have employed satellite-based vegetation indices (normalized difference vegetation index, NDVI) or land-use databases (18), whereas urban geographers have preferred the measurements of proximity (e.g., nearest distance) and gravity (19, 20). With the emergence of ICT, individual-level and street-level data from sources such as Google Street View images may provide new opportunities to move beyond 2D-based greenness measurements (21, 22). In this context, the primary aim of this research is to explore the associations of eye-level greenness and residents' obesity in China, since China is facing rising rates of overweightness and obesity among its citizens (23). China's obese population exceeds that of the United States and ranks first in the world (6). We used Shanghai as the study area since it has a high population density and a green space disparity issue (24). This research was based on a survey of 9,524 respondents from 40 communities in the metropolitan area. We used the technique of deep convolutional neural network architecture to extract eye-level information from Street View images to calculate the visible green index at a vertical level. Additionally, we also considered the normalized difference vegetation index (NDVI) and the accessibility of urban parks to assess both the size and service effects of green space. We are particularly concerned about the relationship between different types of greening levels and obesity.

LITERATURES REVIEW

Built Environment and Public Health

For quite some time, people did not pay attention to the impact of the built environment on residents' health, focusing more on the role of traditional health services. They did not begin to expand the scope to consider the factors affecting residents' health until the 1970's. Whitehead and Dahlgren claimed that the key factors affecting health include genetics, lifestyle, social economy, and environment (25). Evans believes that the built environment can directly affect mental health through six aspects: housing conditions, facility layout, living density, sound environment, air quality and lighting, and regulation and self-control. Mental state, affected by social support and healing, indirectly affects mental health (26). Considering the variety of influencing factors and the complexity of the influencing mechanism, the main influencing factors on resident health in the built environment can be summarized as follows: social environment, physical environment, and access to health and social services (27).

The green space can be defined as follows. Natural vegetation and artificial vegetation are the main forms of land use in urban areas. Green space comprises two types of land: land used for greening within the scope of urban construction land and the area outside the urban construction land that has a good green environment, which positively affects ecology, landscape, and residents' lives. As one of the most critical components of urban space, urban green space can reflect the quality of a city's life to a certain extent, and it is of great significance to the sustainable development of urban ecological environment and the support and promotion of residents' health and well-being. Urban green space provides a variety of ecosystem services (28). Jiang explained the influence mechanism of urban green space on public health in terms of five aspects: promoting physical exercise, soothing mental stress, reducing mental fatigue, providing ecological products and services, and enhancing social capital (29). It is also believed that green space promotes health by reducing stress and remodeling cognition, enhancing physical activity, promoting social interaction, reducing noise, regulating temperature and humidity, and filtering air pollution (10). Other researchers have further concluded that the main health effects of green space are reduced harm to the physical environment, reduced physiological and psychological stress, and promoted health-related activities (such as exercise and social interaction) (30).

With increasing evidence of the association of neighborhood greenness and resident's weight status, there are also some studies examining the association between eye-level neighborhood greenness and people's rising BMI (16, 17). Furthermore, a study using GSV data of Hong Kong shows that children's BMI is lower where the greenery is better around the school environment (16). Li and Ghosh (2018) from Cleveland, Ohio, USA found that street greenery has a stronger effect on women's BMI than that of men. Practically, many green-health-related studies use street view images (17). Lu (2019) used GSV data to determine the effect of eye-level street greenery on physical exercise (31). Helbich et al. found that the depression of the elderly in Beijing can be prevented with a better view green index (32). By comparing GSV data with green space data of other scales, GSV data reflect another special characteristic of green space and provide a new perspective for the study of the relationship between green space and public health (33).

The Association of Greenness and Obesity

Obesity has been a widespread concern shared by many scholars because of the high risk it poses toward causing various serious chronic diseases. Moreover, there have been studies on the relationship between green space and obesity. Some studies have shown that the spatial elements of urban green space relating to obesity include accessibility, scale, frequency of use, and vegetation cover. Sarkar believes that the accessibility of green space is significantly negatively related to BMI, which may be due to the improvement of utilization efficiency of green space with high accessibility and the further reduction of the BMI level by residents using it for physical exercise (34). A study from Denmark (7) shows that access to a garden or living a short distance from green areas is associated with a lower likelihood of obesity. Halonen et al. conducted an 8-year study and found that living far from usable green areas or waterfront in urban areas increases the risk of overweightness (35). Mowafi et al. (2012) found that when the socio-economic status changed, there was no significant correlation between the accessibility of green space and BMI, and the main cause of obesity may be the deficiency of a diet structure of low-income groups (12). Cummins and Fagg (2012) analyzed the data from 2000 to 2007 in the UK and found that the green space scale was significantly related to BMI (11). A study using Dutch national health survey subjects (36) showed that NDVI surrounding greenness within a 300-m buffer zone in residential areas was significantly negatively correlated with overweightness. Tilt et al. considered NDVI and accessibility together and found that in areas with better vegetation cover, the objective accessibility of green space was negatively correlated with the BMI of residents (37). Relationships among green space attributes and BMI varied with age and gender. Green space composition and contiguity were related to BMI for some groups (15).

Greenness Metrics

The mechanism of green space's influence on health is still controversial in the existing research. First, some active leisure activities that may have positive effects on health sometimes do not occur in the green space. For example, in high-density cities such as Hong Kong, active leisure activities rarely occur in green space because leisure space requires more hard-paved surfaces (38). Further, Fong et al. indicate that there may be some deviation in the analysis results using NDVI as the basis for measuring the spatial level of urban green space, owing to the lack of information on natural space quality and the detailed information of tree species or other vegetation (30). Land use data, used to measure the characteristics of green space, sometimes have their defects; they may not provide small-scale vegetation information, including small gardens. Finally, because of the different land classification methods used in different regions, the consistency and comparability of the unified global measurement method of NDVI are lacking, so it is difficult to realize the use of land use data in cross-regional research (10).

Research based on the health benefits of urban green space is well-established but is still in the early stage of development and progress (38). The evaluation system of urban green space spatial elements and the methods of obtaining and processing spatial data are also developing. Feng et al. (2010) claimed that there are differences among the results of a large number of empirical studies, which can be attributed to different methods of measuring green space (8). The spatial data of urban green space are generally sourced from government databases. The accessibility, scale, and density index of green space can be obtained by spatial analysis and processing urban traffic network and land use data. The frequency of green space and the diversity index of spatial utilization can be obtained by field investigation, observation, interview, and GPS positioning sensing. Through the analysis and processing of satellite remote sensing images, the green space index composed of vegetation spectrum, such as NDVI, can be obtained. With the development of 3 s technology, namely remote sensing, geographic information system (GIS), and global positioning system (GPS), the application of space technology, sensor technology, satellite positioning, navigation technology, and digital technology in the collection, processing, and analysis of spatial data of urban green space has been realized. Ye et al. (2018) collected and extracted Google Street View images through a machine-learning algorithm to obtain the View Green Index (VGI) to realize the accurate measurement of visual greening (39).

In summary, although there have been many studies on green space and residents' health, the existing studies cannot effectively reveal the impact of green space on urban health. There are many evaluation systems for green space and health status themselves, and the results obtained by applying different evaluation criteria in different research areas vary. Additionally, there are a few existing research studies that examined the health of green space based on the VGI. Most studies used the NDVI and other indices alone; when using the indicators to reflect the spatial distribution of green space, it is difficult to depict the whole picture of green space characteristics, as street scene greening is more closely related to the daily life of residents. Therefore, using the VGI to determine residents' BMIs as an example, this study examines the influence of green space on urban health. In this study, it was assumed that the green space represented by the VGI has an influence on residents' BMIs, which is different from that measured by the NDVI and spatial distance. The sensitivity varies across populations.

STUDY AREA AND METHOD

Data Source

Data on urban residents come from the World Health Organization's Global Aging and Adult Health Data (Sage, wave 1), which were obtained from 40 communities and 9,524 samples in Shanghai. The communities' areas in our study ranged between 0.022 and 5.607 km^2, and their average size is 1.453 km^2. These samples come from Huangpu District, Hongkou District, Minhang District, Pudong New District, and Qingpu District of Shanghai. Based on the principle of sample heterogeneity, these areas were randomly selected, and 40 communities were divided according to the size and type of communities in different towns or streets. After the screening of effective data, 40 communities and 8,988 samples were designed. The survey collected community information and personal information of residents. Community information included community location, whether that be an urban or another type of community; personal information of residents included information such as age, gender, income, marital status, profession, education level, and so on. The geographical distribution of the community is shown in **Figure 1**. In this study, the height (m) and weight (kg) of residents were calculated to reflect the level of obesity. The higher the indicator of the BMI, the more likely the residents are to be obese, and the unhealthier they are. The formula for calculating the BMI is as follows:3

$$\mathbf{BMI} = \frac{\mathbf{Weight}}{\mathbf{Height^2}} \tag{1}$$

In 2003, the Ministry of Health of China introduced a new method to classify the BMI as per the specific traits of the Chinese population: $18.5 < \text{BMI} \leq 23.9$ indicates normal weight, $24 \leq \text{BMI}$ indicates overweight, $24 < \text{BMI} \leq 27.9$ indicates pre-obesity, and $28 \leq \text{BMI}$ indicates obesity. Based on this, we divided the BMI of residents into three grades: normal ($18.5 < \text{BMI} \leq 23.9$), overweight ($23.9 < \text{BMI} \leq 27.9$), and obese ($28 \leq \text{BMI}$).

Neighborhood Greenness Measurement

View Green Index

In this study, we used the method of Ye et al. (2018) to calculate the VGI; urban roads were selected based on ArcGIS

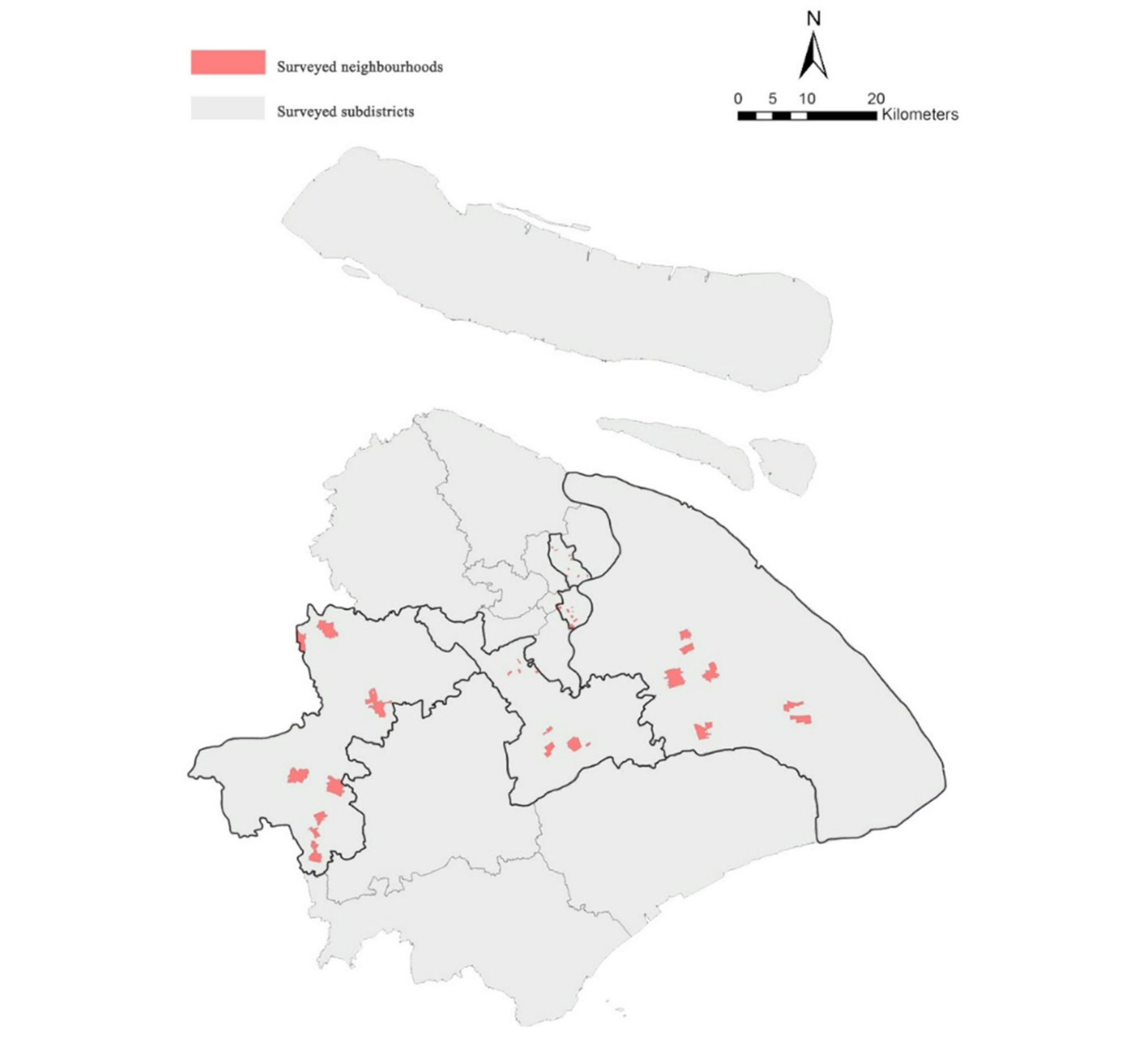

FIGURE 1 | Location of research space unit in Shanghai.

10.3, and the 50-m interval was used to select points on the road. After obtaining the coordinates of the selected points, we used the Baidu map API to grab the street view image of the sampling points, thus obtaining complete street view data. We then imported these data into the open-source project SegNet, used the image segmentation methods based on super-pixels to interpret the image and classify it into color categories through the decoder, and finally analyzed the VGI data of Shanghai according to the calculated color proportion results. The ratio of green plant pixels to total pixels in four selection point images was used to evaluate the street greening level of the point (39), as follows:

$$\mathbf{VGI_i} = \frac{\sum_{j=1}^{4} \mathbf{GreeneryPixels_{ij}}}{\sum_{j=1}^{4} \mathbf{TotalPixels_{ij}}}, \tag{2}$$

where *i* is the selected street view point; *j* refers to separate graphs; *GreeneryPixels* is the number of green pixels in point *i* graph *j*; and *TotalPixels* is the total number of pixels in point *i* graph *j*. In this study, a 1,000-m buffer was drawn based on the community center. The mean values of the VGI of all selected street view points in the buffer range were calculated to evaluate the greening level of each community using the VGI, as shown in **Figure 2**. The research radius of 1,000 m was determined by consulting many previous works of literature (31, 40, 41). Because walking is

FIGURE 2 | The distribution of View Green Index collected from street image in Shanghai.

how residents come into contact with green space and the average daily walking time of most residents is 10 min, within 1,000 m, people will choose walking first (42). We also considered that only 6 out of 40 communities have an area of more than 3.142 km^2; the buffer zone with a radius of 1 km can cover most of the community.

Greenness Exposure Index

The NDVI is calculated from the visible and near-infrared light reflected by vegetation. Healthy vegetation absorbs most of the visible light that hits it and reflects a large portion of the near-infrared light. Unhealthy or sparse vegetation reflects more visible light and less near-infrared light. The relationship is expressed mathematically as follows: NIR is the near-infrared band, RED is the red band; the NDVI value range is (-1, 1). The larger the value, the higher the vegetation cover level. Weier and Herring (2000) classified the NDVI into the following grades:−1–0 represents a water body, 0–0.1 represents rock, sand, and snow plain (barren), 0.2–0.3 represents bush and grassland, and 0.6–0.8 represents temperate and tropical rain

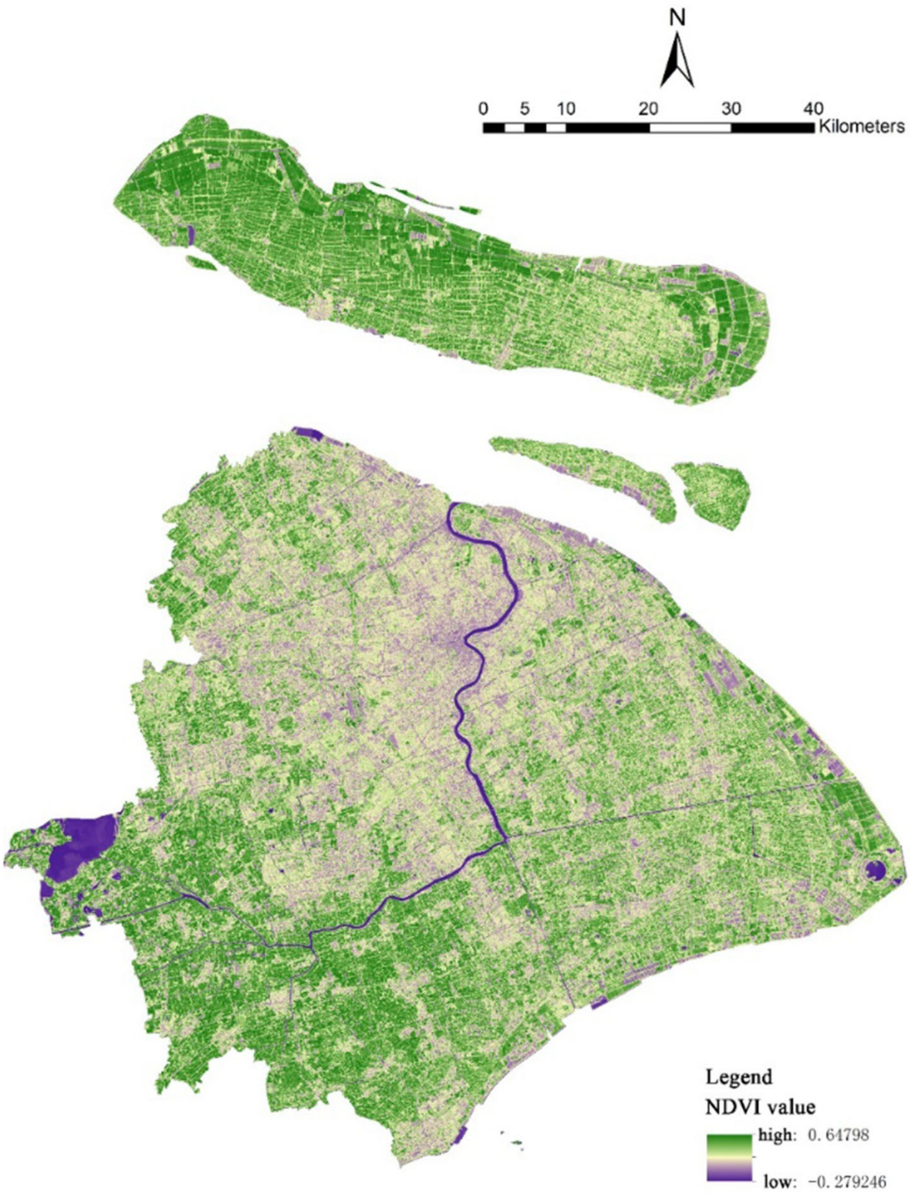

FIGURE 3 | Remote sensing image of NDVI value distribution in Shanghai.

forests (43). The NDVI data belong to the band 4 RED and band 5 NIR, as recorded by the operational land imager of Landsat 8 satellite in Shanghai. The resolution is 30 × 30 m. Using the ENVI5.1 platform, radiometric calibration, atmospheric correction, and other means of pre-processing the original data and the NDVI normalization processing calculation tool, the NDVI data of Shanghai and its distribution remote sensing image were obtained (**Figure 3**). Like the VGI, we calculated the average NDVI in a 1,000-m buffer of communities to evaluate the NDVI status of communities representing greening.

$$NDVI = \frac{NIR - RED}{NIR + RED} \quad (3)$$

Park Accessibility

City parks can provide a suitable environment for leisure and sports activities. Parks are usually used as substitutes for open green spaces in research (39). A community's distance from the city park can represent the accessibility of the park for the community and reflect the contribution of park green space to the health of residents. Using ArcGIS, the nearest distance analysis of existing green space and community boundary was performed, and the nearest distance from the community to the park boundary was obtained. Meanwhile, we calculated the total area of the park in the 1,000-m buffer zone to obtain the scale of green space in the residential environment. The urban parks'

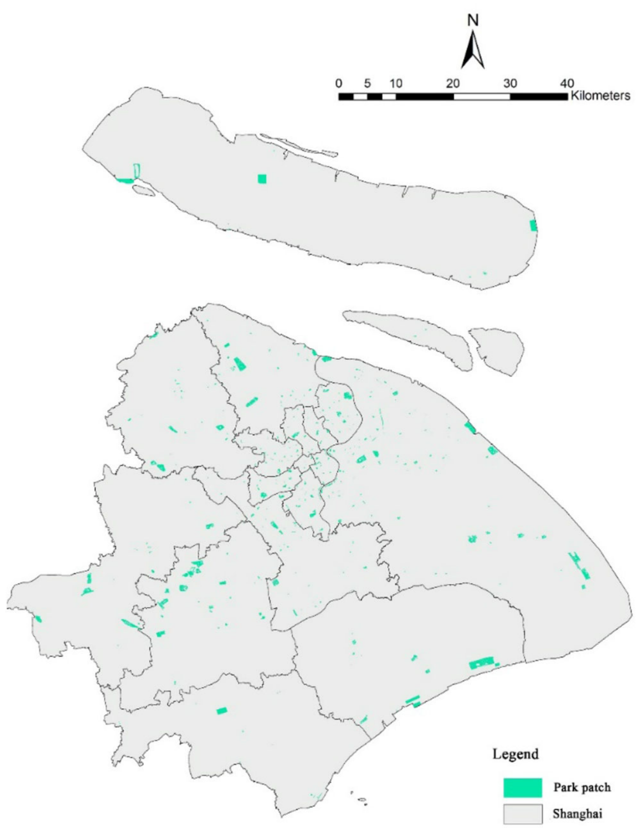

FIGURE 4 | Geographical distribution of urban parks in Shanghai.

data of Shanghai come from its cadastral map, which includes geographic information of 416 urban park patches in Shanghai (**Figure 4**).

Model Specification

Our main purpose was to explore the influence of green space on overweightness or obesity. The "normal" BMI class was used as a reference group, and the other two groups were "overweight" and "obesity." Since our dependent variable is a multinomial and ordinal category variable based on the consideration of green space in different communities, there are no fixed efforts on health. Therefore, the statistical model used in this study was a two-level multilevel mixed-effects ordered logistic regression. The model can be written as follows: where for a series of M independent clusters (residential district), and conditional on a set of fixed effects X_{ij}, a set of cutpoints κ and a set of random effects u_j, z_{ij} are the covariates corresponding to the random effects.

$$\Pr(\mathbf{y_{ij}}=\mathbf{k}\,|\kappa,\mathbf{u_j})=\mathbf{H}(\kappa_\mathbf{k}-\beta\mathbf{X_{ij}}-\mathbf{z_{ij}}\mathbf{u_j})-\mathbf{H}(\kappa_{\mathbf{k-1}}-\beta\mathbf{X_{ij}}-\mathbf{z_{ij}}\mathbf{u_j}) \quad (4)$$

where $j=1,\ldots, M$ clusters (in this case, 20), with cluster j consisting of $i = 1,\ldots, n_j$ observations (in this case, 8,988). The cutpoints κ are labeled $\kappa_1,\kappa_2,\ldots,\kappa_{-1}$, where K is the number of possible outcomes (in this case, 3). $H(\ldots)$ is the logistic cumulative distribution function that represents cumulative probability. Controlled variables reflect the community and personal characteristics of residents, including age, gender, marital, education, income, job, and location of communities. We also added the variable of self-rated health, which is composed of the Likert 5 scale. The results include the subjective scores of residents on their overall health: 1 "very unhealthy," 2 "unhealthy," 3 "general," 4 "healthy," and 5 "very healthy." In this study, "Age" indicates whether the residents are over 60 years old, according to the WHO age classification standard, where 1 refers to "beyond 60" and 0 refers to "under 60." "Gender" is the dummy variable of residential gender, where 1 refers to "male" and 0 refers to "female"; "Marital" is the dummy variable of resident marital status, where 1 refers to "married" and 0 refers to "otherwise"; "Education" is the dummy variable of residential education, where 1 refers to "middle school and above" and 0 refers to "otherwise"; "Income" is divided by whether the income of residents accounts for the top 25% of the total sample, where 1 refers to "yes" and 0 refers to "no"; "Job" is the dummy variable of employment, where 1 refers to "employed" and 0 refers to "otherwise"; "Place" is the dummy variable of communities, where 1 refers to "urban area" and 0 refers to "rural area."

EMPIRICAL RESULTS

Descriptive Results

In **Table 1**, we found that people with a normal BMI accounted for nearly half of the sample and that people who were overweight were twice as common as those who were obese. In terms of age, 50% of the samples were over 60 years old, meaning that the majority of the elderly population were included in the sample. The distribution of gender was relatively even, with females being slightly higher in number. The majority of the samples had spouses. In terms of individual socioeconomic characteristics, the education level of most people was lower than that of junior high school, which is understandable in combination with the fact that most were elderly. It was found that the economic conditions of residents were not too poor, which may be because nearly half of the sample members were still employed while others possibly had other sources of income. It was gratifying that most people were satisfied with their overall health, but 1 in 10 people still perceived their health as not ideal.

Regarding green space, the average NDVI of the research communities is low, which indicates that the vegetation coverage is poor. NDVI remote sensing image (**Figure 3**) can also directly reflect this point; that is, only the communities in Qingpu District have a higher vegetation coverage while other communities have a lower vegetation coverage due to a higher urbanization level of the built environment. Considering that some studies show that 15% of the VGI is the minimum acceptable value and that 25% of the VGI offers the most comfortable appearance, we can claim that the average VGI of the research communities is in the middle level (44). Overall, the research buffer zones cover a large area of parks, but the average nearest distance between the community center and the park is 2 km, which is a relatively long distance.

Our research hypothesis is that the impact of the green vision rate on residents' health is different from that of green space from other perspectives, and the impact is also different in different populations. So, we first build a basic model to analyze the health differences of different people and then add different green features from different perspectives to see whether green space impacts residents' health and whether it has a different impact on different people. Based on equation 4, first, we introduced the control variables to form the basic model (Model 0). Considering that the NDVI, the park area, and the nearest distance from the community to the park also reflected the state of green space around the community, they are described as per the characteristics of land cover, which is different from the evaluation of green space from the vertical direction by the VGI. Therefore, it is necessary to compare the effect of the VGI and the other three green space evaluation indexes on the BMI.

In the basic model, two variables, "distance to the park" and "park area within 1,000-m buffer zone," were added to analyze the impact of park conditions and living environment on the BMI of residents through model (1); adding the variable "NDVI of 1,000 m buffer zone," we obtained model (2) to analyze the living environment vegetation cover's effects on the BMI. "VGI of 1,000-m buffer zone" was used as an independent variable to construct model (3) to observe the influence of green space from the three-dimensional perspective represented by the VGI on the resident BMI. Finally, we added all the variables representing the green space level and the interaction terms of income level with park distance and the NDVI to analyze whether the effect of park conditions and vegetation coverage level on the BMI is affected by income (Model 4), because the residents' choice of community is usually independent of the VGI but in consideration of community vegetation coverage and surrounding urban parks.

Regression Results

The results of the multilevel mixed-effects ordered logistic regression are shown in **Table 2**. As depicted in Model 0, the male and the married individuals tended to become overweight/obese, which may be due to the impact that emotional state has on people's lifestyles. The more educated the people are, the less likely they are to be overweight/obese. This is because people with good education may have better eating habits. People without work are more likely to be obese than those with work. People without work may have a lot less physically intensive activity. People with better self-rated health are more likely to be of normal weight, which may be due to how the obesity constitution has brought some negative health effects on people who have worse self-rated health.

Models 1–3 estimated the impact of green space from different angles on residential health. The coefficient of "distance" was tested to be negative and significant at the 1% level, while the coefficient of "park area" was not significant in Model 1. It was found that the longer distance from parks relieves the risk of obesity or overweightness. This result seems to contradict our existing cognition of green space. Considering the large number of elderly people in the study, the reason for this result may be that the elderly generally do not use the park for physical exercise, but tend to rest and engage in social activities, so the walking process to and from the park has an impact on their physical health (34). In Model 2, the coefficient of the "NDVI" variable was not significant; that is to say, no direct correlation between the NDVI and residents' health was found, which is inconsistent with our expected results, because we initially thought that individuals surrounded by higher NDVI spots were more likely to not be overweight. In Model 3, the "VGI" yields negative and significant coefficients at the 10% level, indicating that growth in the VGI helps obesity control. The addition of variables of green space hardly changed the influence

TABLE 1 | Descriptive statistics of variables.

	N[a]	%[b]
Dependent variable		
BMI Class (Mean = 0.665)	8,988	100.00
Normal	4,228	47.71
Overweight	3,493	28.86
Obesity	1,267	14.10
Sociodemographic variables		
Age (Mean = 0.501)	8,988	100.00
Under 60	4,490	49.96
Beyond 60	4,498	50.04
Gender (Mean = 0.459)	8,988	100.00
Female	4,861	54.08
Male	4,127	45.92
Marital (Mean = 0.848)	8,988	100.00
Married and cohabitation	7,621	84.79
Otherwise	1,367	15.21
Individual SES variables		
Education (Mean = 0.273)	8,988	100.00
Middle school and above	2,453	27.29
Otherwise	6,535	72.71
Income (Mean = 0.312)	8,988	100.00
Top 25%	2,801	31.16
Otherwise	6,187	68.84
Job (Mean = 0.448)	8,988	100.00
Respondent was employed	4,035	44.89
Otherwise	4,953	55.11
Place (Mean = 0.565)	8,988	100.00
Urban	5,087	43.40
Rural	3,901	56.60
Health		
Self-rated health (Mean = 3.515)	8,966	100.00
Very unhealthy	69	0.67
Unhealthy	751	8.37
General	3,368	37.56
Healthy	4,080	45.51
Very healthy	707	7.89
Green Space	**Mean**	**Std. Dev.**
NDVI (obs = 8,988)	0.213	0.076
VGI (obs = 8,276)	0.208	0.086
Area of Parks (obs = 8,988)	37,780.49	72,072.11
Nearest distance to parks (obs = 8,988)	1,813.429	2,163.851

[a] *N represents actual number of observations.*
[b] *Percentages reflect sampling weights from complex survey design.*

TABLE 2 | Results of multilevel mixed-effects ordered logistic regression model.

Independent variable	Model (0)		Model (1)		Model (2)		Model (3)		Model (4)	
	Dependent variable		Dependent variable		Dependent variable		Dependent variable		Dependent variable	
	BMI (3 classes)		BMI (3 classes)		BMI (3 classes)		BMI (3 classes)		BMI (3 classes)	
	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.	Coef.	Std. Err.
Age	0.035	0.044	0.038	0.044	0.039	0.044	0.069	0.046	0.082	0.048
Gender	0.123**	0.041	0.122**	0.041	0.122**	0.041	0.142***	0.043	0.138**	0.045
Marital	0.168**	0.058	0.172**	0.058	0.172**	0.058	0.150**	0.061	0.108	0.063
Education	−0.243***	0.051	−0.247***	0.051	−0.247***	0.051	−0.237***	0.051	−0.253***	0.053
Job	−0.111*	0.047	−0.105**	0.047	−0.100**	0.047	−0.112**	0.049	−0.115**	0.052
Place	0.052	0.080	−0.001	0.090	−0.052	0.097	0.099	0.086	0.110	0.098
Income	−0.042	0.046	−0.043	0.046	−0.045	0.046	−0.053	0.047	−0.034	0.061
Self-rated health	−0.076**	0.027	−0.076**	0.027	−0.076**	0.027	−0.081**	0.028	−0.102***	0.030
Distance			−0.004**	0.002					−0.005***	0.014
Area 1,000 m			0.067	0.043					−0.004	0.004
NDVI 1,000 m					−1.038	0.558			4.784**	2.156
VGI 1,000 m							−1.019**	0.406	−1.298***	0.404
income_distance									0.005***	0.001
income_ndvi									−0.354	0.202
	Wald chi² (8) = 63.49		Wald chi² (10) = 70.30		Wald chi² (9) = 66.89		Wald chi² (9) = 74.41		Wald chi² (14) = 96.78	
	Prob>chi² = 0.0000		Prob>chi² = 0.0000		Prob>chi² = 0.0000		Prob>chi² = 0.0000		Prob>chi² = 0.0000	
	N = 8,966		*N* = 8,966		*N* = 8,966		*N* = 8,257		*N* = 7,583	

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

of other control variables. It is noteworthy that when comparing the basic model results, despite significant coefficients of green space-related variables, the coefficient symbol of "place" has changed in the model with urban park and vegetation coverage as independent variables, indicating a latent moderation effect in variables. But the coefficient symbol of "place" has not changed in the model with the VGI as the independent variable. We thought that the variable "income" that affected residence may have an intermediary effect in the model, so we added the interaction terms of "actual value of income" and "NDVI" and "actual value of income" and "park distance" to the model. The reason why the interaction term of "actual value of income" and "VGI" is not included is that people usually do not choose their residence according to street greening, and the street greening is rarely affected by the change of built environment. This may also be the reason why the coefficient symbol of the variable "place" in the third model has not changed.

It is seen that "place" may influence the health effect of green space. Since this variable reflects the individual income and the green space status of a community, which also relates to income, Model 4 included green space-related variables and the interaction of income and green space. Given the lack of correlation between the VGI and income and the insignificant coefficient of "park area," only "income $\times$ distance" and "income $\times$ NDVI" were included. In Model 4, the coefficient of "distance" was negative and significant, while the coefficient of "income $\times$ distance" appears to be positive and significant. This shows that income affects the effect of distance from the park on the BMI. It is said that in the low-income group, the farther the distance to the park, the greater the probability that the BMI of the residents is normal, while in the high-income group, the closer the distance to the park, the lower the probability of obesity of the residents. This may be because, among the high-income groups, people are more willing to go to the nearest park for exercise activities. Increasing income may discourage the "distance" variable from obesity restraints. Calculating the income threshold, a longer distance promoted the deterioration of obesity when individuals' income exceeded an actual value, and that is an income level that all employed individuals could achieve. Thus, for employed residents, shortening the distance to parks helped them stay healthy, while for those who were unemployed, the opposite was true. The coefficient of "NDVI" was positive and significant, while the coefficient of "income $\times$ NDVI" was insignificant. This shows that income also affects the effect of vegetation coverage on the BMI, and in the lower-income group, a high NDVI increases obesity, while in the higher-income group, a high NDVI environment makes people's BMI more normal, while the effect of the moderation of income could not be evaluated. "VGI" yielded negative and significant coefficients, just like in Model 3. Residents with higher VGI were more unlikely to be overweight or obese.

CONCLUSION AND DISCUSSION

Differentiated outcomes of regression in BMI groups may result from the uneven distribution of individual income and green space of communities. In this study, the VGI was introduced as the index of green space to study its influence on community residents' BMI, and the effect of green space on residents' health was evaluated from a new perspective. Through regression analysis, this study reveals the relationship between the VGI and residents' health. This study argues that street scenery has an impact on residents' health. The greening in street scenery reflects the overall level of street greening around the community, and street greenery is an important aspect of green space that residents come into contact with daily. The VGI is more closely correlated with residents' health than park green space or the NDVI. By comparing with the NDVI data widely used in the previous literature and the distance from the community to the park, this study reveals that the VGI yields different outcomes from the NDVI and green space distance, i.e., vertical greening has an impact on the health of residents. Because VGI, NDVI, and urban park spaces affect and measure the characteristics of green space from different approaches, the VGI is a good supplement to the above in the study of the health effects of existing green space. We should comprehensively understand the effect of green space on health from the aspects of horizontal and vertical greenery as well as the accessibility of green spaces.

We focused on the health represented by BMI and drew the above conclusions. However, because of the complexity of health evaluation criteria, there are defects in using a single BMI index to evaluate the health status. More health indicators should be used to further strengthen the conclusion of this study. According to the sample collection process, because of the high proportion of the elderly population in the research community, the aging of the community was more significant. Before the regression analysis, the community already somewhat contained aging characteristics. It is known that the impact of community green space, including VGI and NDVI, on residents' health may improve residents' health level by promoting activities in green space. To study the effect of activity time on the health of green space, we can introduce the variables of residents' activity time and their intersection with the characteristics of green space in the future.

The initial objective of this research was to examine the association of neighborhood greenness and residents' obesity in a high population density context. There are three different types of greenness features involved in our study, including green access, green exposure, and the VGI. Our research was built upon a large-scale survey from the WHO, and some key findings from a multilevel mixed-effects ordered logistic regression estimation are reported as follows. (1) It was found that, of the three types of greening levels, only the VGI consistently posed a negative effect on overweightness and obesity, indicating that eye-level neighborhood greenness could efficiently promote the physical activity of residents aimed to control their weight. (2) There was no significant relationship between the NDVI and the BMI in the beginning, but after we added the intersection of income and the NDVI, we found that the high-income group with better vegetation in their communities might have a better health status. (3) It was found that green proximity had a significant effect on overweightness and obesity, but the negative correlation was unexpected, indicating that people closer to the park were associated with a higher likelihood of obesity. When we accounted for the intersection of income and distance, the above issue was well-explained. The results showed that Shanghai residents with high income and normal body weights live close to city parks. Our results meaningfully complement the existing literature in two respects.

First, we provided evidence that neighborhood greenness has a preventive effect in weight management for high-density areas. It was found that all aspects of horizontal and vertical green levels and proximity to the same have an impact on body weight in case of a lack of green space resources per capita. Although we found that the correlations of some variables were incorrect, it is because China was established in the early stage of rapid urbanization, and a mixed U-shaped curve was formed in which the rich are overweight and the poor are becoming obese (45, 46).

Second, our results also confirmed that the VGI of the deep learning approach using Baidu Street View images could effectively capture the eye-level greening features in high-density areas of the population (21); such VGI can effectively promote walking and other physical activities to prevent obesity. The traditional measurement method is mainly based on the two-dimensional space, assuming that residents will use the urban green space nearby, but this may not be true for individuals using green space for recreation (47). Such VGI based on big data provides the possibility of measuring the greening level in 3D, and street view and satellite-derived green space measures represent different aspects of natural environments (48). Many studies have shown that this type of perceived greening can improve physical activities (49).

Given this information, we acknowledge that there are still some limits in this study. For instance, the sage survey fails to perfectly represent the overall greening condition of Shanghai. Moreover, the NDVI feature may vary across seasons, and the VGI measures the green space along the road network based on street view images. We acknowledge that such data are affected by the sampling distance and the street view data themselves. Also, the street view image is formed across the year, and it is hard to identify the season of images, which makes the time of VGI data uncertain.

Finally, our study offers important implications for future policies. China's green space planning system should be further improved, considering the supply and management of vertical greening. In such a high-density built environment area as Shanghai, the establishment of a new green space is a huge challenge for planners. To improve vertical greening, we can try to increase the used vertical space, such as building elevation as the target zone. Road greening can be developed to improve road users' feelings in places where plants near residential areas will not be intrusive to urban traffic efficiency. Although large park green space has a strong externality and can increase housing prices (50), our research found that the size of the park has nothing to do with the weight of residents. Therefore, health-oriented planning should promote the construction of a green space system and increase the type of green space and encourage a small and decentralized greenway network system, which is conducive to multiple physical activities, such as walking, cycling, and others. Meanwhile, it is necessary to strengthen the community vegetation coverage of living environments.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

AUTHOR CONTRIBUTIONS

YX: writing - original draft, writing – review, and editing. YZ: formal analysis. YS: methodology for deep learning. PT: data analysis. XK: funding acquisition, validation, conceptualization, and supervision. All authors contributed to the article and approved the submitted version.

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Important Elements and Features of Neighborhood Landscape for Aging in Place: A Study in Hong Kong

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With rapid growth in the aging population around the world, the promotion of aging in place has become more significant in recent years. Many neighborhood landscape elements and features have been revealed by accumulating research findings to be critical to aging in place. However, they are usually studied separately or in small groups. Little has been done to examine the relative importance of these elements and features when brought together, from the older adult's point of view. In this context, the current study investigated the perceived importance for older adults of 22 selected neighborhood landscape elements and features. A questionnaire survey was conducted in 17 public rental housing estates in Hong Kong with proportions of older residents (aged 65 or above) between 20 and 40%. According to the 426 collected samples, older adults considered as highly important landscape elements and features that contribute to comfort and help them avoid hazards, such as good ventilation, protection from severe sunshine/rain, body support, and good hygiene, while elements were thought to potentially bring hazards while not being necessities for older adults' outdoor experience were considered least important, including portable chairs, outdoor tables, plants that can be touched, closeness to children's playgrounds, small spaces for solitude, water features, and fitness equipment. After integrally interpreting the findings regarding perceived importance with other collected data, some landscape design suggestions are generated to supplement existing guidelines and recommendations concerning older adults' well-being and quality of life. These findings can inspire future research and landscape design that prioritize promoting aging in place.

Keywords: neighborhood, landscape elements and features, perceived importance, older adults, aging in place

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INTRODUCTION

The world's population is aging rapidly. In 2019, about 9% of the global population was aged 65 or above. This proportion is estimated to reach 12% by 2030 and 16% by 2050. Furthermore, projections indicate that the population of aged people will be twice as many as that of children aged 0–4 and will exceed youths aged 5–14 and 15–24, respectively, by 2050 (1). Although an aging population places increasing demands on caring for older adults, it does not make sense to institutionalize them all. In fact, most older adults would prefer not to leave communities that they are familiar with (2). Considering the decaying health condition of most older adults, outdoor space near their residences would play an important role in promoting aging in place, i.e., to support them in living independently in their neighborhoods and homes for as long as possible.

Since the 2000s, there has been a sharp increase in research in this field (3). On the one hand, functional and cognitive impairment, chronic diseases, a diminishing social network, and a low level of physical activities have been identified as hindered aging in place (4–7). On the other hand, neighborhood outdoor environments have been revealed as better for older adults' well-being through helping retain their preferred lifestyles, social connections, and sense of control, together with better clinical outcomes compared with their institutionalized counterparts (8). If an environment is enjoyable, and hence induces enjoyable activities inside it, it would contribute to users' quality of life (9, 10). In such relatively small-scale outdoor environments, landscape elements, and features can be closely experienced and thus be critical for promoting aging in place.

OUTDOOR LANDSCAPES FOR OLDER ADULTS

According to mounting research findings, outdoor spaces, especially those with natural elements, have been broadly proven to be contributive to older adults' physical, mental, and social well-being and to further enhance their quality of life (11–15). Actually, once they have stepped into nature, older adults may immediately feel relieved, away from the indoor sources of depression (16). In most cases, the neighborhood outdoor landscape contains natural elements such as plants and water and likely attracts small animals. These are good sources of various sensory stimulations. According to Cox et al. (17), less sadness is experienced when being in a garden or a place with sensory stimulations than when indoors. Even for individuals with dementia, their psychological symptoms decrease after accessing a natural setting (18). If the landscape is properly designed and equipped with facilities, it can encourage physical activities that can sustain and even improve the physical and mental health of older adults (19). In many cases, simply walkable green spaces near residences can positively influence the longevity of older adults in urban areas (20). In addition, inter-personal interactions and activities in the outdoor spaces can provide social support to older adults, thus fostering a sense of belonging or community that can be good for their well-being as well (21).

Although simply viewing a landscape with natural elements is already contributive to human beings' well-being (22–24), there will be much greater well-being benefits and a richer experience when a person is physically in a space with landscape design. Therefore, accessibility and safety should be ensured first to support older adults with declining health conditions (25, 26). Accessibility generally refers to the availability of spaces and certain facilities, connectivity with destinations, and barrier-free design solutions (27). Safety mainly concerns crimes and accidents while using outdoor spaces (28, 29).

Aside from such fundamental factors, landscape design elements have also been discussed in responding to older adults' specific needs. For instance, with reduced strength and stamina, older adults may not be able to walk as far or as fast as younger ones. Correspondingly, they need more resting facilities, shelters, and shade where they can take rests and be protected from unfavorable weather conditions (10). They may also have difficulties in keeping good balance and thus need handrails or other facilities as support (30). Furthermore, many older adults have deteriorated eyesight or visual impairments. This, together with reduced balance, make it easy for them to fall and get hurt due to unleveled pavements, illusions of level changes due to shadows or different colors of paving materials, or glare from paving materials (30). In addition, life after retirement usually makes older adults feel bored, and they need some interests in life or to engage in social activities (31). In supporting these needs, ornamental plants can not only provide sensory stimulations and enjoyments but can also trigger certain interactions between people, thus enhancing social networking (10, 32). People moving around and children playing in a neighborhood also effectively add liveliness to the spaces. Older adults commonly like to watch these people, and may incidentally meet friends, which also contributes to their quality of life (33). Besides, if outdoor space design could provide older adults with more of a sense of control and choice, they would get more satisfaction. For instance, portable chairs that allow people to sit in the positions and orientations they like, tables that provide support for food and drinks or reading, and different paths to take could be included (30).

Based on a growing body of evidence, design guidelines on outdoor landscapes for older adults have emerged. Most guidelines cover the above-mentioned design aspects and provide practical recommendations (30, 34, 35). However, with the constraints of site conditions and available resources for each project, it can be very challenging to meet all design requirements or recommendations in practice, except for some fundamental requirements like barrier-free design, leveled pavements, and sufficient lighting. Usually, it is also hard to judge which landscape elements and features are more important, as most of them are studied separately by different researchers and with different research methodologies. These may hinder the utilization and well-being benefits of landscape (36, 37). The above review implies that older adults' concerns related to community landscape design should be studied comprehensively. For instance, when different landscape elements and features are put together, which of them are more important for older adults? Therefore, this study was conducted to investigate the perceived relative importance of landscape elements and features in the eyes of older adults, focusing on neighborhood outdoor landscapes, with the hope of supporting landscape research and design that aims to promote aging in place.

METHODOLOGY

Hong Kong Situation

The study was conducted in Hong Kong, a city facing serious aging problems, like many other cities in the world. According to the Census and Statistics Department of the HKSAR government, the proportion of people aged 65 and above reached 17.0% of the entire population in mid-2018 (38), and it is expected to reach 31.1% (2.37 million in total) by 2036 and 36.6% (2.59 million) in 2066 (39). As revealed by a government survey, older adults in Hong Kong would like to age at home and live in a familiar

TABLE 1 | Basic information of 17 selected PRH estates.

No.	Authorized party	Name of estate	Year of intake (establishment)	Population aged 65 and above*	Total population*	% of aged residents
1	HA	Shui Pin Wai Estate	1981	2,691	6,725	40.0
2	HA	Ap Lei Chau Estate	1980	5,272	14,504	36.4
3	HA	Lok Wah South Estate	1982	4,452	12,843	34.7
4	HA	Lai Kok Estate	1981	2,224	6,488	34.3
5	HS	Cho Yiu Chuen	1976/78/79/81	2,424	7,159	33.9
6	HA	Shun Lee Estate	1978	4,110	12,363	33.2
7	HA	Fuk Loi Estate	1963	2,260	6,999	32.3
8	HA	Sha Kok Estate	1980	4,384	14,522	30.2
9	HA	Cheung Sha Wan Estate	2013	800	3,344	23.9
10	HA	Hung Hom Estate	1999/2011	1,553	6,623	23.5
11	HA	Oi Tung Estate	2001	2,254	8,028	28.1
12	HA	Upper Ngau Tau Kok Estate	2002/09	4,151	15,004	27.7
13	HA	Fortune Estate	2000	1,115	4,489	24.8
14	HA	Po Tin Estate	2000	2,174	10,782	20.2
15	HA	Lai On Estate	1993	715	2,957	24.2
16	HA	Ko Yee Estate	1994	761	3,326	22.9
17	HS	Ka Wai Chuen	1984/87/90/93	1,511	6,928	21.8

According to population census 2016 (44).

community until they need residential care services: 96.4% of 1,130 elderly participants did not intend to move into a local residential elderly care facility (40). This is supported by findings of a more recent survey in Hong Kong (41).

With the dense and compact development mode in Hong Kong, outdoor spaces within residential estates are critical for aging in place and the well-being of older adults, as most of them are traffic-free. Among different types of residential developments in Hong Kong, public rental housing (PRH) estates developed by the Hong Kong Housing Authority (HA) and the Hong Kong Housing Society (HS) always provide such spaces at a relatively sufficient proportion of the total site area. Meanwhile, the HA and HS are also major providers of rental housing for senior citizens in Hong Kong. According to the 2016 Population By-census, among the 2,100,126 total population living in PRH, 392,575 (18.7%) were older adults aged 65 or above, comprising 36.7% of all elderly people in domestic households in Hong Kong (42). The HA and HS's role in supporting the aging population will become more critical in future, and so will outdoor landscape design in PRH estates.

Estate Selection

Among the 199 PRH estates in Hong Kong (190 developed by the HA and 9 by the HS), most open spaces were developed in similar ways, except for accommodating fewer water features in recent years and some style evolutions on plant species selection (43). In this study, 17 PRH estates were selected, mainly based on the proportion of aged residents and forward-looking considerations: eight with 30–40% aged people among residents, representing an overall population scenario in the next half-century or even a longer period, and the remaining nine with 20–30% aged people among residents to represent a scenario of the near future (**Table 1**). The distribution of these estates is shown in **Figure 1**. Examples of typical landscape elements and features in these estates are shown in **Figure 2**.

Questionnaire Design

A questionnaire was designed to collect data mainly about perceived importance for a set of landscape elements and features in neighborhood outdoor spaces. The landscape elements and features were extracted from various design guidelines and published studies concerning outdoor landscape elements and features for aged people, while those already commonly agreed as fundamental and that have been incorporated in PRH estates, such as barrier-free accessibility and a non-slippery ground surface, were excluded. Each of the 22 final listed items' association with the well-being and quality of life of aged people has been identified or proven by empirical studies. These landscape elements and features were categorized into Convenience, Comfort, Sense of safety, Sense of control, Stimulation, and Social support to facilitate discussion (**Table 2**).

Specifically, Convenience covers two sub-categories, namely, supportive distance, and supporting elements. Supportive distance mainly concerns the distance between major destinations and facilities that older adults would need to visit, e.g., shops and public toilets; together with allocation of neighborhood outdoor spaces, i.e., the distance between spaces and major pedestrian routes (45, 46, 49, 50). Supporting elements refers to those that have been shown by some studies to help older adults keep their body balance and avoid falling (51).

FIGURE 1 | Distribution of selected PRH estates (Source of base map: https://www1.ozp.tpb.gov.hk/gos/default.aspx).

FIGURE 2 | Typical landscape elements and features in selected PRH estates (photoed by author).

TABLE 2 | Selected landscape elements and features.

Category	Sub-category	Landscape elements/features in questionnaire	Studies on health influence & design guidelines of landscape element/feature
Convenience	Supportive distance	Close to major pedestrian route	(45)
		Close to shops (convenient purchase of food and drinks)	(46) (47) (48) (49) (50)
		Close to public toilet	(10, 12)
	Supporting elements	Body support (bench, planter edge, railing, etc.)	(51) (30)
		Outdoor table (independent or attached to a bench)	(30)
Comfort	Weather-related solutions	Avoidance of severe sunshine/rain	(10) (52)
		Good ventilation	(49)
	Hygiene	Good hygiene	(49)
Sense of safety	–	Can see what is happening from outside (to decide whether to enter or not, timely emergency treatment, etc.)	(37)
		Can see what is happening nearby	(37)
		Quiet environment	(49)
Sense of control	Privacy	Small space for solitude	(30) (53)
	Have choices	Multiple entrances/exits for a space	(30)
		Portable chair	(30) (53)
Stimulation	Sensory stimulation	Open view (can see distant plants, buildings, mountains, etc.)	(30) (53)
		Water feature (pool or water fountain, etc.)	(30) (53)
		Ornamental plants	(27) (10) (54) (32)
		Plants that can be touched	(30) (55)
		Visible dynamic elements (e.g., activities of other people, people/vehicles passing by, small animals, dynamic water, water fountain, plants moving in the wind, etc.)	(30)
	Exercise stimulation	Fitness equipment	(19) (56) (49)
Social support	–	Large space for gathering	(57) (49)
		Close to children's playground	(10)

However, in Hong Kong, older adults tend to equip themselves with canes, walkers, and wheelchairs to avoid potential falls. Hence, supporting elements in this study refers to body support, like benches, planter edges, and railings, or elements like outdoor tables that help relieve users' burden (30, 51).

Comfort covers aspects of weather-related solutions and hygiene. The sub-tropical climate in Hong Kong makes it hot and humid, with a lot of showers, during long summers. Therefore, elements that can protect people from severe sunshine/rain and spaces with good ventilation (air flow) are critical to enable people to stay outside (10, 49, 52). In addition, hygiene would also affect people's comfort through visual and osphretic aspects (49). Poor hygiene conditions may also spread germs and affect the health of vulnerable older adults. This is also a concern of older PRH residents (41).

Regarding Sense of safety, it is generally quite safe in PRH estates, as security guards patrol frequently and CCTV covers all public areas. Therefore, safety in this study is mainly about whether older adults can receive instant help in case of accident and whether they are forewarned of potential hazards. Under such circumstances, the in-outward visual connections of a space could be critical (37). Besides, quiet environments can lower the alert level and make people feel safe and relaxed (49). Although it is arguable that people may feel upset in a completely quiet environment, such a case seldom exists in outdoor spaces in developed areas in Hong Kong due to its high population density.

Research has found that older adults with a higher sense of control usually enjoy better health (58). Therefore, it would be good if outdoor landscapes could provide a certain extent of privacy by creating small spaces where one or two people could stay alone and away from disturbances (30, 53). Besides, providing different route choices to a space can also enhance the sense of control (30). In addition, portable chairs are also considered contributive to sense of control, as discussed above (30, 53).

The category of Stimulation covers sensory and exercise stimulations in this study. Sensory stimulations include landscape elements and features like open views, water features, ornamental plants, plants that can be touched, and visible dynamic elements (10, 27, 30, 32, 53). Among these, touching plants has been proven to be soothing and therapeutic (55). However, to prevent mosquito problems, most landscape property managements apply pesticides on plants and warn people about this with signage boards in Hong Kong. Therefore, Hong Kong people tend not to touch plants in reality. Nonetheless, behavior may not reflect attitudes or willingness. Therefore, this item is still included to examine older adults' attitudes. Additionally, fitness equipment is included under exercise stimulation as facilitators of physical activities for older adults (59–62).

Social support mainly refers to meeting with people and friends in the neighborhood, such as gathering with friends in relatively large outdoor spaces in the estates, or watching children play, which add liveliness in older adults' lives (10, 57). It is critical for older adults to keep connections with others in society (57). Among various connections, intergenerational programs have become popular among caregiving organizations for older adults (63). Although positive intergenerational relationships are mainly observed in elderly caring facilities, it is suspected to be valid in neighborhoods with mixed generations as well.

For each of the 22 landscape elements and features, participants need to assign a mark on a scale from 0 to 10, where a higher mark represents higher perceived importance. To assist in analyzing the possible reasons for perceived importance, the time and days that older people would use neighborhood outdoor spaces and their outdoor activities within their estates were also investigated in the questionnaire. Activities were first extracted from the author's previous studies on older adults in Hong Kong (36, 37) and were supplemented by pilot studies in the selected PRH estates. These activities were shown in a multiple-choice question in the questionnaire. Participants could tick or supplement to indicate all of their activities in neighborhood outdoor spaces. In addition, demographic information such as age, gender, self-evaluated health, physical impairment, household composition, and period living in the estate was also collected.

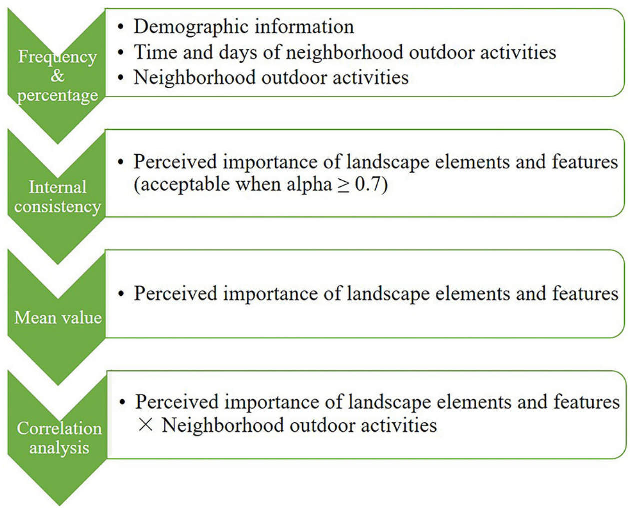

FIGURE 3 | General analysis process.

Data Collection and Processing

The survey was conducted during June and July 2019 in the selected 17 PRH estates. During the survey, people seemingly aged 65 or above were approached randomly and were filtered out if they were not residents in the current estate or aged under 65. During the survey, participants were encouraged to share reasons for their answers and insights into their neighborhood outdoor spaces. Participants were allowed to quit during the survey as they liked. The planned sample size in each estate follows the proportion of the older-resident population in that estate to the sum of those in all 17 estates, based on a total targeted sample size of 420 [considering potential loss in sorting, the targeted sample size was set as 1.1 times the original 381, which was calculated with 5% confidence interval, 95% confidence level, and a target population of 42,851 (64), and rounded up to nearest 10]. Collected data were processed with IBM SPSS 22. The general analysis process is shown in **Figure 3** and will be elaborated on below.

RESULTS

A total of 426 valid samples were collected. Among these, 241 were female (56.6%) and 185 were male (43.4%). This is generally consistent with the overall demographic situation among older adults in Hong Kong by mid-2018 (65). Of the participants, 41.5% claimed that they did not have any chronic diseases; 12.9% thought their health condition was very good, 46.9% good, 33.1% generally ok, and 7% poor or very poor. The most mentioned chronic diseases were cardiovascular and cerebrovascular (39.9%), followed by orthopedics diseases (36.1%) and diabetes (9.6%). In terms of physical impairment,

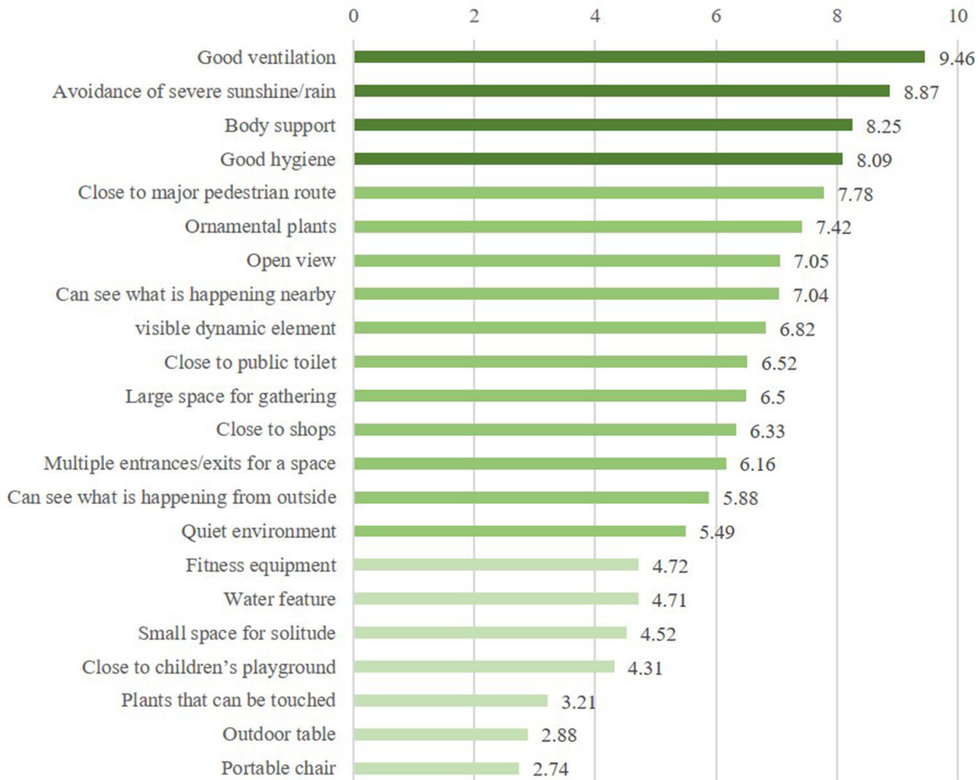

FIGURE 4 | Perceived importance of each landscape element/feature (ranked).

58.2% of participants claimed that they did not suffer from any such impairment. Among various impairments, impaired mobility was most common (31%). Regarding household composition, 34.5% of participants lived alone, while the rest lived with other people like children, spouses, parents, and domestic helpers.

By the time of this survey, 99.3% of participants had lived in their estates for more than 1 year and 84% for more than 10 years. Most participants used open spaces in their estates frequently: 63.6% used such spaces more than once every day, 27.9% once every day, and 8.4% once to twice a week or less. They visited these outdoor spaces on any day throughout a week, except a bit less on public holidays (88.5%). Considering a single day, around 70% participants visited the outdoor spaces during 9 a.m.−12 noon and 3–5 p.m., around 40% came out in early mornings before 9 a.m., ∼20% stayed outside during noon hours, while <20% stayed outside after 6 p.m. These responses indicate that most participants visited outdoor spaces in their estates frequently and were familiar with these spaces and the facilities within them and thus that their replies to our survey could be considered reliable.

The internal consistency of the 22 landscape elements and features was examined with a reliability analysis in SPSS. The result for Cronbach's alpha is 0.713, which indicates an acceptable internal consistency among the 22 items. The perceived importance of the 22 landscape elements and features is represented by the mean values of the item scores received (**Figure 4**). Generally speaking, landscape elements and features that related to Comfort, i.e., good ventilation, avoidance of severe sunshine/rain, and good hygiene, together with body support under Convenience fall into the high range (>8.0), except that in Comfort, a few items under each of the rest categories fall into the medium (5.0–8.0) and low (<5.0) ranges in terms of perceived importance among participants. Additionally, the frequency and percentage of each type of activity are summarized in **Table 3**. Those taken part in by 50% or more of the participants are mainly passive activities.

DISCUSSION AND DESIGN IMPLICATIONS

Landscape Elements and Features With High Perceived Importance

Based on literature review, landscape elements and features that related to Convenience were expected to receive higher rankings in perceived importance. Surprisingly, only Body support under this category was scored as having high perceived importance, while all three items under Comfort were scored highly. To explore the possible reasons for this, correlations between items with perceived importance >8.0 and activities conducted by participants were examined. According to **Table 4**, activities that significantly correlated with items under Comfort were

TABLE 3 | Older residents' activities in outdoor spaces in PRH estates (popular activities are shown in bold).

	Passing by	Sitting	Watching others' activity	Chatting	Waiting for others	Basking	Enjoying the cool	Reading/writing/drawing/watching mobile	Resting/napping	Contemplation	Eating/drinking	Smoking
Frequency	84	**391**	**239**	**324**	19	62	**312**	59	71	6	40	35
Percent	19.7	**91.8**	**56.1**	**76.1**	4.5	14.6	**73.2**	13.8	16.7	1.4	9.4	8.2
	Watching plants/animals	**Listening to animals**	**Leisure walking**	**Stretching**	**Exercising**	**Walking exercise**	**Taking care of grandchild**	**(Watching) chess/card playing**	**Listening to music/opera**	**Singing/playing instrument**	**Drying clothes**	**Other**
Frequency	**209**	166	**215**	150	108	49	6	39	46	3	12	13
Percent	**49.1**	39	**50.5**	35.2	25.4	11.5	1.4	9.2	10.8	0.7	2.8	3.1

relatively more popular among participants in PRH outdoor spaces (see **Table 3**). This indicates a high representativeness of these correlations among older adults in their residential outdoor spaces in general.

Good ventilation was negatively correlated with Pass by, which implies that if participants find that the ventilation of a space is good, they tend to stay in it. Furthermore, good ventilation promotes various relaxing and passive activities, like enjoying the cool, watching plants/animals, watching others' activity, and listening to animals. Under such circumstances, people may have an experience similar to meditation and be more sensitive to direct sensations (66). During hot days, good ventilation with breezes can effectively strengthen evaporation on the skin, hence improving thermal comfort (67). This could encourage leisure walking and stretching as well as outdoor activities in general among older adults.

Avoidance of severe sunshine/rain in outdoor spaces seems to be more influential on activities with a potentially long duration, like sitting, watching others' activity, chatting, enjoying the cool, watching plants/animals, listening to animals, and leisure walking. It appears critical to activities that rely heavily on vision, such as eating/drinking and playing chess/cards, as older adults can be easily affected by strong light or glare due to deteriorated vision and visual impairment (68). Besides lighting conditions, rain can also affect older adults' use of outdoor spaces. Most of the participants told us that they would stay indoor if it was raining. However, if a shower came when they were already outside, they would be easily caught by the rain, as many of them move slowly and are afraid of falling due to rushing or the wet ground. Therefore, if there are shelters that can protect them from the showers, older adults can enjoy their outdoor activities without worrying about sudden changes in the weather.

High perceived importance of Good hygiene is probably rooted in participants' consciousness that a space with poor hygiene could harm their health. Since maintaining health is critical and even challenging to most older adults, it is understandable that they would not put themselves at such risk. Regarding associations with activities, Good hygiene is positively correlated with rest, watching plants/animals, listening to animals, leisure walking, and exercise. Actually, some participants expressed reservations about birds or other animals, for these animals may spread bird flu or other diseases, and their feces can stain the environment. This could partially explain why older adults emphasize the hygiene of an outdoor space while they enjoy small animals around them.

Another highly scored element is Body support under the category of Convenience. This item covers various seating facilities and alternatives such as planter edges that are suitable for sitting and elements (railings) at waist or back height to support leaning. It is more associated with static activities, especially long-lasting ones, e.g., watching others' activity, enjoying the cool, watching plants/animals, and listening to animals (**Table 4**). In order to help sustain older adults' self-esteem, it is better to integrate these body support elements into general landscape design instead of making them specifically for older adults.

TABLE 4 | Correlation between items with perceived importance >8.0 and activities (significant correlations are shown in bold).

	Passing by	Siting	Watching others' activity	Chatting	Waiting for others	Basking	Enjoying the cool	Reading/writing/drawing/watching mobile	Resting/napping	Contemplation	Eating/drinking	Smoking
Good ventilation	**−0.114***	**0.152****	**0.190****	−0.003	−0.056	**0.096***	**0.302****	0.060	0.063	−0.013	0.023	0.020
Avoiding severe sunshine/rain	−0.030	**0.163****	**0.233****	**0.116***	0.059	−0.092	**0.268****	0.076	0.010	−0.002	**0.108***	0.057
Body support	−0.063	**0.192****	**0.177****	0.087	**−0.125****	0.035	**0.317****	0.058	−0.011	−0.004	0.040	−0.009
Good hygiene	−0.005	−0.008	−0.067	0.007	0.002	0.085	0.085	−0.050	**0.198****	0.038	0.050	−0.015

	Watching plants/animals	Listening to animals	Leisure walk	Stretching	Exercising	Walking exercise	Taking care of grandchild	(Watch) chess/card play	Listening to music/opera	Singing/playing instrument	Drying clothes	Other
Good ventilation	**0.208****	**0.169****	**0.252****	**0.153****	0.040	−0.011	0.037	0.013	0.074	−0.080	0.017	0.057
Avoiding severe sunshine/rain	**0.151****	**0.158****	**0.190****	0.057	0.045	0.045	−0.022	**0.105***	0.052	**−0.106***	−0.052	−0.043
Body support	**0.189****	**0.206****	**0.207****	0.083	**0.114***	0.042	0.027	−0.011	0.042	−0.040	−0.032	−0.038
Good hygiene	**0.136****	**0.097***	**0.114***	0.041	**0.103***	0.082	−0.082	−0.025	0.049	**−0.096***	0.030	**−0.106***

*$p < 0.05$ (2-tailed), **$p < 0.01$ (2-tailed).

Landscape Elements and Features With Low Perceived Importance

Landscape elements and features with an average mark of <5.0 include Fitness equipment, Water feature, and Plants that can be touched under the category of Stimulation, Small spaces for solitude and Portable chairs under Sense of control, Close to children's playground under Social support, and Outdoor tables under Convenience. These outcomes are surprising, as all of these items have been stressed in various design guidelines for older adults (12, 30, 53, 69). Again, associations between these items and activities, together with comments received during the surveys are examined to facilitate interpretation (**Table 5**).

Regarding Fitness equipment, some participants commented that it was more suitable for healthy and young people with a higher level of strength. Some also mentioned that many types of fitness equipment were over-sized for them. Older adults who often do stretches and exercise may not have such problems and also use fitness equipment more (**Table 5**). Nonetheless, demands for properly designed fitness equipment should not be denied. A good approach would be to provide aging-friendly fitness equipment to encourage exercise among older adults and further contribute to their well-being through a more physically active lifestyle (70, 71).

Water features, Close to children's playground, Plants that can be touched, Outdoor tables, and Portable chairs are considered less important by participants mainly due to safety concerns. For Water features, some participants told us that children would play in the water and wet the ground nearby, which would be slippery. Similarly, children may cause other hazards if they play close to older adults. For instance, children would occasionally bump into people when running around. This could injure older adults seriously. One participant told us that she was once knocked down by a child in her estate and suffered a broken bone. Despite these issues, children's contribution to liveliness is highly appreciated in these estates with high proportions of older adults. For Plants that can be touched, relatively active people, like those who take part in exercise or stretching, may be more sensitive to lively elements and appear to consider it somewhat important (**Table 5**). In reality, few people take action although many said that they would like to touch beautiful or lovely plants if they came across them, mainly due to the application of pesticides discussed above.

Regarding outdoor tables, participants shared that some people partied around them until midnight, made a lot of noises, and dirtied the place; in some other cases, there were quarrels between different people competing to use the tables. In most cases, outdoor tables were dismantled by property management in the end. For portable chairs, even though many participants reflected that seating is inadequate in their estates, they did not like portable chairs. They commonly worried about falling while sitting down or standing up or tripping over while walking if the chairs were not fixed. Seemingly the only case that outdoor tables and portable chairs are in need is for (watching) playing chess/cards (**Table 5**). This is supported by frequent observations of older adults who play chess/cards on benches or even on planter edges and attract crowds around them.

TABLE 5 | Correlation between items with perceived importance <5.0 and activities (significant correlations are shown in bold).

	Passing by	Sitting	Watching others' activity	Chatting	Waiting for others	Basking	Enjoying the cool	Reading/writing/ drawing/watching mobile	Resting/ napping	Contemplation	Eating/ drinking	Smoking
Fitness equipment	**0.106***	–0.078	**–0.133****	0.059	–0.040	0.039	–0.059	–0.071	0.050	–0.007	0.011	0.027
Water feature	0.055	0.050	0.036	0.036	–0.055	0.013	0.039	–0.008	0.013	0.085	0.062	0.070
Small space for solitude	**0.106***	–0.012	–0.070	**–0.154****	0.089	0.083	**–0.117***	0.066	0.000	–0.007	–0.067	0.022
Close to children's playground	0.024	–0.083	0.033	0.078	–0.094	0.054	0.040	–0.027	0.025	0.024	**0.143****	0.030
Plants that can be touched	**0.106***	–0.078	**–0.133****	0.059	–0.040	0.039	–0.059	–0.071	0.050	–0.007	0.011	0.027
Outdoor table	0.080	–0.077	–0.043	–0.013	**0.153****	0.000	**–0.114***	0.038	0.032	–0.033	–0.081	0.035
Portable chair	0.065	–0.018	**–0.103***	0.008	–0.029	0.070	–0.066	–0.021	–0.060	–0.070	–0.012	0.095
	Watching plants/animals	**Listening to animals**	**Leisure walking**	**Stretching**	**Exerciseing**	**Walking exercise**	**Taking care of grandchild**	**(Watching) chess/card playing**	**Listening to music/opera**	**Singing/playing instrument**	**Drying clothes**	**Other**
Fitness equipment	–0.049	–0.017	–0.127	**0.153****	**0.281****	0.021	–0.022	0.049	0.045	–0.016	0.016	0.006
Water feature	**0.109***	**0.138****	0.035	0.071	**0.170****	–0.058	–0.036	**0.100***	0.009	0.032	0.068	–0.049
Small space for stay alone	–0.055	–0.057	**–0.147****	–0.094	**–0.097***	0.054	–0.048	–0.088	0.000	0.012	–0.077	–0.060
Close to children's playground	**0.121***	**0.153****	0.053	0.072	0.078	–0.036	**0.106***	0.011	0.037	–0.008	0.030	0.064
Plants that can be touched	–0.049	–0.017	**–0.127****	**0.153****	**0.281****	0.021	–0.022	0.049	0.045	–0.016	0.016	0.006
Outdoor table	–0.064	–0.039	–0.062	0.002	0.011	0.006	–0.027	**0.181****	–0.039	0.090	0.046	0.028
Portable chair	**–0.117***	**–0.130****	**–0.185****	0.001	0.034	–0.035	–0.009	**0.173****	0.020	0.015	–0.061	–0.079

*$p < 0.05$ (2-tailed), **$p < 0.01$ (2-tailed).

Considering Small spaces for solitude, four out of five significant correlations between this item and activities are negative (**Table 5**). This indicates that older adults tend to be aggregation-oriented, even with little interaction. One reason for this would be that many of them live alone (34.5% of the participants in this study). Such an isolated or semi-isolated life could be stressful for many people, especially vulnerable older adults (72, 73). It may also lead to loneliness and depression and affect their quality of life (74). From this perspective, older adults need a sense of been connected with society, which could be largely achieved by spending time with others in neighborhood outdoor spaces. Another possible reason could be that older adults would not feel released in an outdoor space that is similar to or even smaller than their residence in size. Therefore, this study reveals that compared to small spaces with high privacy, older adults prefer spacious ones that can support a certain extent of gathering.

Landscape Elements and Features With Medium Perceived Importance

The remaining landscape elements and features had medium perceived importance, including Close to major pedestrian route, Close to public toilet, and Close to shops under the Convenience category; Ornamental plants, Open view, and Visible dynamic element under Stimulation; Can see what is happening nearby, Can see what is happening from outside, and Quiet environment under Sense of safety; Large space for gathering under Social support; and Multiple entrances/exits for a space under Sense of control.

Seemingly, items under Convenience and Stimulation are relatively important within this range. They mainly represent supportive distance and the interestingness of views. If considered integrally with Body support, this implies that if sufficient body support elements or facilities were provided, older adults would not mind walking farther. This could be a valuable reference for neighborhood outdoor space design and even for community planning with special concerns about older adults. Views inwards to and outwards from a space could be easily realized simultaneously when creating open views and could be better integrated with locomotional access, i.e., entrances to spaces. Regarding sharing a space with others, older adults in this study showed less concern. This can be explained by their low intention to spend time alone in outdoor spaces as discussed above. However, they seem not to be proactive for Social support either, as many thought themselves too old and weak to engage in organized activities. The only significantly correlated activities with this item are chatting ($r = 0.333$, $p = 0.000$), rest/nap ($r = 0.125$, $p = 0.010$), and exercise ($r = 0.122$, $p = 0.012$). Chatting and exercising are commonly observed to be conducted by different people together, often with interactions. Resting/napping in a crowd or next to other people may contribute to a sense of safety or being connected to the society. It seems that older adults in the studied estates tend to make minimal effort to maintain social connections and avoid loneliness, which has been commonly agreed as a predictor of functional decline (6, 7).

Design Implications

Our findings regarding the perceived importance of neighborhood landscape elements and features for older adults generate some landscape design suggestions. These could supplement existing guidelines and recommendations concerning aging-friendly landscape design:

- Weather-related solutions such as good ventilation and weather protection should be provided carefully so as to improve the general outdoor experience for older adults. This would be especially important for places with hot seasons and high annual rainfalls.
- Water features and children's playground can add a lot of interest and liveliness to neighborhoods, which could greatly enrich older adults' outdoor experience. However, they may also become hazards to older adults. Therefore, it is better to locate them at a certain distance from major routes and spaces that are heavily used by older adults while providing visual and acoustic connections in between. Level differences, short fences, or hedges between these spaces may help to achieve such safe connections.
- The safety issues of any portable facilities or elements, like portable chairs, should be carefully considered. In order to ensure the safety of older adults while fulfilling the needs of other age groups in neighborhoods, it is suggested to locate such facilities away from major routes and spaces that are used heavily by older adults.
- The boundaries of each single space should be designed to ensure good in-outward visual connections to support timely help when needed and to avoid any corner or spot that may lead to hygiene problems. These approaches can also contribute to security in outdoor spaces, especially those that lack CCTV coverage. It would be good to integrate space boundaries with natural elements so as to enrich interest and strengthen the well-being benefits of outdoor spaces.
- The sizes of facilities should be carefully decided or adjusted for older adults rather than simply applying standard ones. This is especially important for fitness equipment and benches, which could bring a lot of benefits and are in great need.

LIMITATIONS

Neighborhood outdoor spaces are complex systems that involve numerous interactive factors. Although the landscape elements and features investigated in this study are extracted from a comprehensive literature review and are supplemented by initial site observations, there may still be important ones for aging in place yet to be covered. Besides, this study focuses on PRH estates, which leads to a relatively limited diversity in older residents, landscape designs, and property management. If older adults from other socio-economic groups and different types of residential developments such as private ones could be included, the findings would be enriched and more comprehensive for neighborhood landscapes. Furthermore, this study emphasizes the subjective perceptions of participants. The cross-sectional data employed in this study illustrate such perceptions at a certain point in time. However, perceived importance may evolve with the development of the entire society. To further understand the evolution of perceived importance over time, longitudinal data would be necessary. Moreover, the rigor of the study could be strengthened if supported with objective measurements and analyses on the landscape elements and features. When research on this topic goes deeper, different characteristics of older adults could be further discussed to generate more specific and detailed design recommendations. These would be potential directions for future research in this field.

CONCLUSION

This study investigated the perceived relative importance of 22 neighborhood landscape elements and features from the perspective of older adults. It reveals that older adults tend to judge the importance of any landscape element or feature upon comprehensive evaluation of the potential benefits and hazards it would bring, especially emphasizing comfort and safety.

Landscape elements or features that contribute to comfort and help avoid hazards, like good ventilation, avoidance of severe sunshine/rain, body support, and good hygiene, are considered highly important by older adults. Sufficient provision and proper design of these are critical for older adults so that they can use outdoor spaces or avoid difficulties in moving around in their neighborhoods or avoid being attacked by germs, which may threaten their well-being and quality of life. Therefore, these are found to be fundamental landscape elements and features for older adults and should be given priority in neighborhood landscape design.

In contrast, any landscape element or feature that may bring hazards while not being a necessity for older adults' outdoor experience is considered least important. This group comprises portable chairs, outdoor tables, plants that can be touched, closeness to a children's playground, small spaces for solitude, water features, and fitness equipment. If safety concerns could be addressed properly, these landscape elements and features would still be appreciated by older adults.

In between the above two clusters are landscape elements and features that are perceived as of medium importance by older adults. They commonly have alternatives and are not considered necessities. Being close to major routes, ornamental plants, open views, visual contacts inward toward and outward from a space, visible dynamic elements, availability of public toilets, a large space for gathering, being close to shops, multiple entrances to a space, and a quiet environment all fall within this group. These elements and features are not that fundamental but would affect the richness and convenience of the outdoor experience of older adults to a certain extent, especially through contact with nature.

Based on our findings of the perceived relative importance of these neighborhood landscape elements and features, some landscape design suggestions were generated to supplement existing guidelines and recommendations concerning older adults' well-being and quality of life. These will be valuable for neighborhood landscape research and for designs that prioritize promoting aging in place effectively.

DATA AVAILABILITY STATEMENT

All datasets generated for this study are included in the article/supplementary files.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Human Subjects Ethics Sub-committee (HSESC) of THEi, Hong Kong S.A.R. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

AUTHOR CONTRIBUTIONS

The author designed the study, participated and monitored data collection, conducted data analyses, data interpretation, and prepared this article.

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frontiers in Public Health

REVIEW
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A Review of Advancement on Influencing Factors of Acne: An Emphasis on Environment Characteristics

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Background: Acne vulgaris is known as a commonly-seen skin disease with a considerable impact on the quality of life. At present, there have been a growing number of epidemiological, medical, demographic and sociological researches focusing on various influencing factors in the occurrence of acne. Nevertheless, the correlation between environmental factors and acne has yet to be fully investigated.

Objective: To assess the impacts of individual, natural and social environmental factors on acne and to construct a framework for the potential impact of built environment on acne.

Methods: A thorough review was conducted into the published social demographical, epidemiological, and environmental studies on acne through PubMed, Google Scholar and Web of Science, with reference made to the relevant literature.

Results: The influencing factors in acne are classed into four major categories. The first one includes individual socio-economic and biological factors, for example, gender, age, economic level, heredity, obesity, skin type, menstrual cycle (for females), diet, smoking, cosmetics products, electronic products, sleep quality and psychological factors. The second one includes such natural environmental factors as temperature, humidity, sun exposure, air pollution and chloracne. The third one relates to social environment, including social network and social media. The last one includes built environmental factors, for example, population density, food stores, green spaces, as well as other built environment characteristics for transport. Acne can be affected negatively by family history, overweight, obesity, oily or mixed skin, irregular menstrual cycles, sugary food, greasy food, dairy products, smoking, the improper use of cosmetics, the long-term use of electronics, the poor quality of sleep, stress, high temperature, sun exposure, air pollution, mineral oils and halogenated hydrocarbons. Apart from that, there are also potential links between built environment and acne.

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Conclusions: It is necessary to determine the correlation between the built environment and acne based on the understanding of the impact of traditional factors (sociology of population and environment) on acne gained by multidisciplinary research teams. Moreover, more empirical studies are required to reveal the specific relationship between built environment and acne.

Keywords: acne, sociology of population, natural environment, social environment, built environment, green spaces

INTRODUCTION

Chinese cities face many health challenges posed by rapidly changing urban environments (e.g., air pollution, water pollution, zoning and mix use of land, reduction of vegetation coverage and growing population density) and lifestyles (e.g., lacking physical activity, unbalanced diets, tobacco and alcohol use), especially non-communicable chronic diseases, such as cardiovascular disease, cancer, respiratory diseases, diabetes and mental illness, which have replaced infectious diseases as major contributors to the overall disease burden (1). Many skin diseases are also non-communicable chronic diseases, especially acne that mainly occurs on the face, which is easily affected by external factors.

Acne is a chronic inflammatory skin disease involving the sebaceous glands. Four major pathogenesis are involved in the development of androgen-induced increased sebum hyperproduction, altered follicular keratinization, inflammation and Propionibacterium acnes (P. acne) (2, 3). It is also affected by environmental pollution, social environment, changes of dietary structure and lifestyle, for example, worsening air pollution, the intake of sweets, staying up late, social network and social media. Thus, the prevalence of acne increases year by year. According to a systematic analysis for the Global Burden of Disease Study, in 2010, the prevalence of acne among all the population in the world was 9.38%, ranking the eighth in the world (4). From 2006 to 2016, the prevalence of acne increased by 5.1% (5). In the meantime, in the US, the median cost per person per 7 months for acne treatments approved by the US Food and Drug Administration was $350–3,806[1] (6). Because of its high prevalence and recurrence, acne patients have suffered from the corresponding economic burden. In addition, although acne is not a life-threatening disease, it damages the appearance, which might leave scars on patients if not treated in time. Moreover, for young men and women, discosmetic dermatosis can easily lead to inferiority, even affecting the employment and marriage of patients. According to the study in China, 30.8% acne patients reported that acne had a negative impact on their quality of life (7). Several studies showed that people with acne had lower self-confidence, the difficulty of making friends, challenges of going to school, and the trouble of finding a job (8, 9). Moreover, acne patients have a higher propensity of underlying mental disorders, including anxiety, depression and suicide (10, 11). The prevalence of acne can not only impact the cost of drug treatment, but also the psychological disorders associated with acne and quality of life.

Built environment is defined to include all buildings, spaces, and products that are built or modified by humans. There is growing evidence that the built environment affects health in different ways and mechanisms (12), especially chronic diseases such as obesity (13), mental health (14), cardiovascular disease (15), and respiratory health (16). Acne is a chronic disease in which both environmental and genetic factors interact (17). Therefore, it might also be affected by the built environment. However, previous acne epidemiological studies mainly focus on individual factors (such as family history, diet, lifestyle, occupation, and psychological factors) and other natural and social environmental factors (such as air pollution and social network) (18, 19), there is very limited research that examines whether a relationship exists between the built environment and acne. In order to fill up this gap, this article will first do a comprehensive review on the basis of the previous studies of sociology of population, epidemiology, and environmental factors, and further build a framework for the potential impact of built environment on acne for the future research.

SEARCH STRATEGIES AND SELECTION OF STUDIES

We searched all publications included in the electronic databases of PubMed, Google Scholar and Web of Science (from 2000–present). The search stratagem used the term "acne vulgaris (or acne)," with the following combinations: epidemiology, prevalence, Propionibacterium acnes (or P. Acnes), sociology of population, gender, age, hormones, diet, sweets, milk, dairy, greasy, dairy products, spicy, chocolate, glycaemic index, smoking, tobacco, cosmetics, electronic productors, overweight, obesity, mental health, mental disorder, stress, economic, skin type, menstrual cycle, exposure, climate, environment, temperature, humidity, sun, pollution, chloracne, social environment, social network, social media, and built environment. Furthermore, in order to avoid missing relevant literature, we also reviewed the reference lists of the identified papers and manually searched for additional publications. Next, we evaluated the title and abstract of each article based on the inclusion criteria. The full text review was then conducted to determine whether the article met all criteria. Inclusion criteria included: (1) Being written in English, (2) Epidemiological

[1]Spironolactone is $350, oral antibiotics are $501, topical antibiotics are $920, topical retinoids are $1,805, topical combination antibiotics are $2,282, topical combination antibiotics and retinoids are $3,770, the median cost for isotretinoin in males and females are $3,227 and $3,806 respectively.

studies of acne. Exclusion criteria included: (1) respondents with systemic disorders (such as cardiovascular, respiratory, urinary, reproductive and endocrine diseases, etc.)[2]. (2) studies that did not focus on acne. After searching the literature, there were few relevant studies on built environment and acne, only one study about built environment and skin cancer was found. Research found that the occurrence of acne was strongly attributed to the exposure of skin in the natural environment, the obesity and psychological issues, which could be affected by the built environment factors. In order to establish an indirect relationship between built environment and acne, the search stratagem also used the term "built environment," with the following combinations: obesity, overweight, mental health, anxiety, depression and suicide. Inclusion criteria included: (1) Research written in English, (2) original articles. Exclusion criteria included: studies that did not have a significant focus on built environment and obesity, mental health. We initially selected 158 studies based on the titles and abstracts. After reading the full texts, a total of 80 articles met all the criteria and were included in the review. All the 80 studies identified were quantitative (**Figure 1**). Sample size ranged from 50 to 2472004.

RESULTS

The factors that affect acne are classified into four main categories: individual's socio-economic and biological factors, natural environmental factors, social environmental factors and built environmental factors.

Individual's Socio-Economic and Biological Factors

With the rapid urbanization process, there are large-scale migrating and aging populations, changes in dietary structure and lifestyle, and social inequality, leading to a high incidence of chronic diseases (20). As one of the highly recurrent chronic diseases, acne to a large extent is also affected by the relevant demographic and sociological factors, including demographic characteristics, physiological factors, lifestyle and psychological factors (**Figure 2**, Table 1 in **Appendix**).

Gender

There are differences in endocrine levels between the genders, resulting in differences in the prevalence of acne. The epidemiological survey of acne among undergraduates in the North East China showed that the total prevalence of acne among adolescents was 51.30% (52.74% in males, 49.65% in females) (21). The overall prevalence of acne among European aged 15–24 years was 57.8% (58.28% in males, 56.97% in females) (22). An epidemiology in Singapore showed there were more males than females suffering from adolescence acne (61.3 vs. 38.8%) and more females suffering from post-adolescence acne (69.0 vs. 31.0%) (23). The above studies indicated that more males than females suffered from acne during adolescence and more females than males suffered from acne during post-adolescence.

[2]If the topic of studies was not only associated with acne but also other diseases, there might exist confounding effects issues in between.

Age

The epidemiology of acne continues to evolve with changes in hormone levels that vary with age. An Italian study of pediatric outpatients aged 9–14 found that 34.3% patients had acne, with the lowest prevalence rate of 6% at age 9, and the incidence of acne increased to 36.3% after the age of 13 (24). From the prevalence of acne among Chinese adolescents, we found increased age was related to higher prevalence and severity of acne vulgaris: 15.6, 44.9, and 70.4% for 10, 13, and 16 years old (25). The European study showed the prevalence of acne was highest at the age of 15–17 and decreased with age (22). These studies confirmed that acne was more common during adolescence.

Economic Level

According to family income and regional characteristics, urban residents can be divided into poverty, low-middle income, middle-high income and wealthy groups (26). There were differences in the medical services enjoyed by patients at different economic levels, which might affect the prevalence of acne. According to the Canadian study, only 17% of low-income people earning <$ 20,000 referred a dermatologist, while 24% of high-income people earning more than $ 80,000 consulted a dermatologist (27). Furthermore, there are differences in the prevalence of acne between urban and rural areas. Dreno et al. found acne patients were more likely to live in urban areas with higher socio-economic status (28).

Heredity

In clinical work, children of acne patients tend to suffer from acne. Heredity plays a dominant role in the occurrence of acne, especially in severe acne with nodules, cysts and scars. A study of twin models in the UK found that 81% acne variants were caused by genetics and family history, proving that acne have a significant genetic effect (17). An Italian study found that moderate to severe acne is closely related to family history of first-degree relatives (29). An epidemiological study in Iran also showed that the severity of risk of acne increased with the number of family members with acne history, especially a mother with acne history had the greatest impact on acne severity of next generation (30). Studies in China (21) and Europe (22) have found similar results. Other studies demonstrated that the family history of acne was associated with early onset of acne, more skin lesions, and difficult treatment (31). He et al. conducted on a cohort study in the Han population and found that identify two new susceptibility loci at 11p11.2 (damage-specific DNA binding protein 2) and 1q24.2 (selectin L) that are involved in androgen metabolism, inflammation processes and scar formation in severe acne (32).

Overweight and Obesity

Obesity has become a global public health crisis. In China, 46% of adults and 15% of children are obese or overweight. There is a significant relationship between the growing prevalence

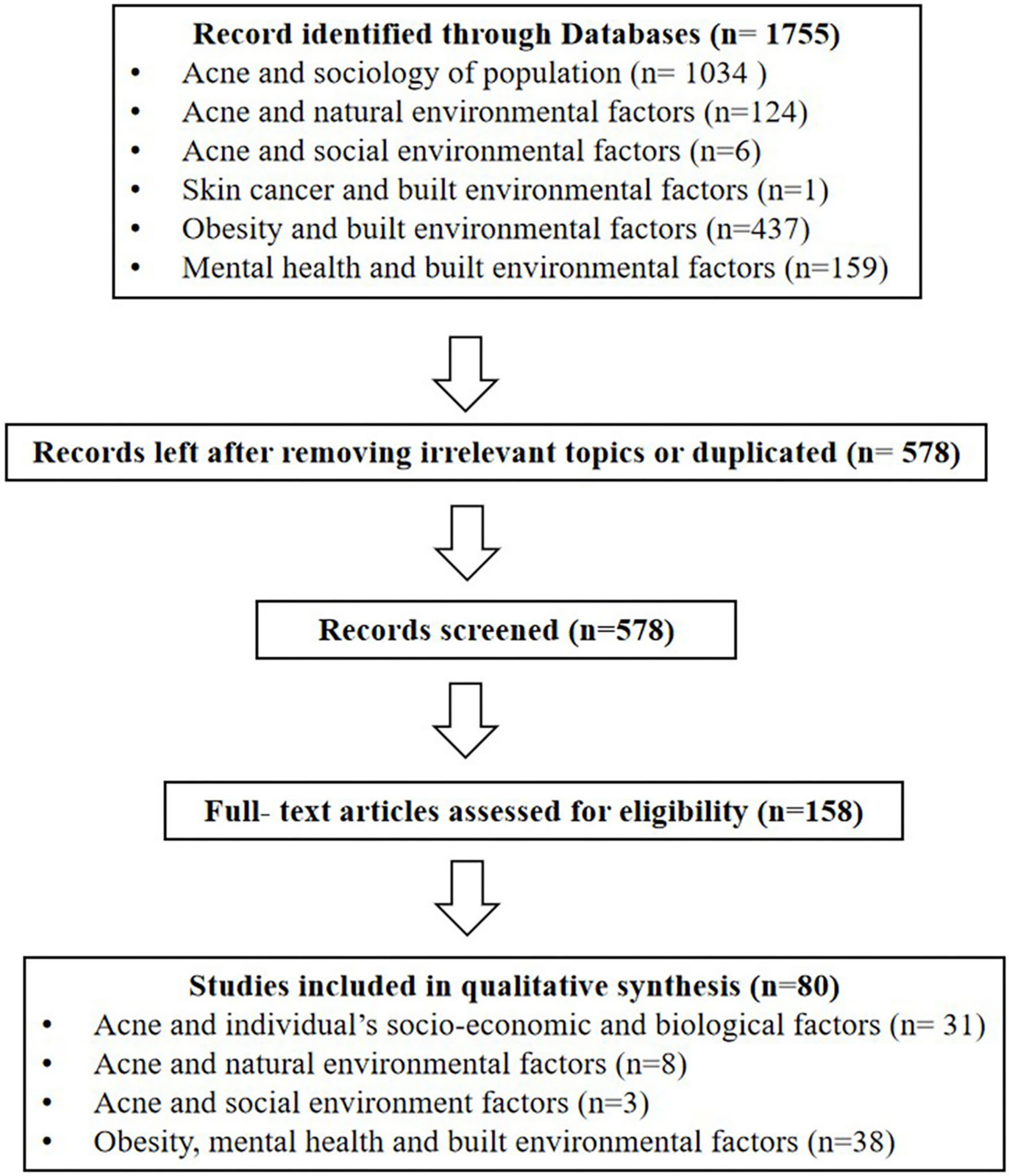

FIGURE 1 | Illustrates the study inclusion and exclusion process.

of obesity and chronic diseases (33). Increased secretion of the insulin-like growth factors—1 (IGF-1) in the body (34, 35) and insulin resistance are possible mechanisms by which obesity affects the occurrence of acne (36). In insulin resistance, decreased sensitivity leads to increased insulin release, which in turn leads to increased production of IGF-1 (34). There were studies demonstrated that overweight and obesity (Body Mass Index, BMI $\geq$ 25 kg/m^2) were positively correlated with an increased risk of acne (37–39). However, a study in Taiwan, China, indicated that BMI was negatively associated with the number of acne lesions from moderate to severe post-adolescent acne among Taiwanese women aged between 25 and 45 years (40). Recently a nationwide study of 600,404 adolescents indicated overweight and obesity were inversely associated with acne in a dose-dependent manner. In this case, the proportion of adolescents with acne decreased gradually from the underweight to the severely obese group (males, from 19.9 to 13.9%; females, from 16.9 to 11.3%) (41). However,

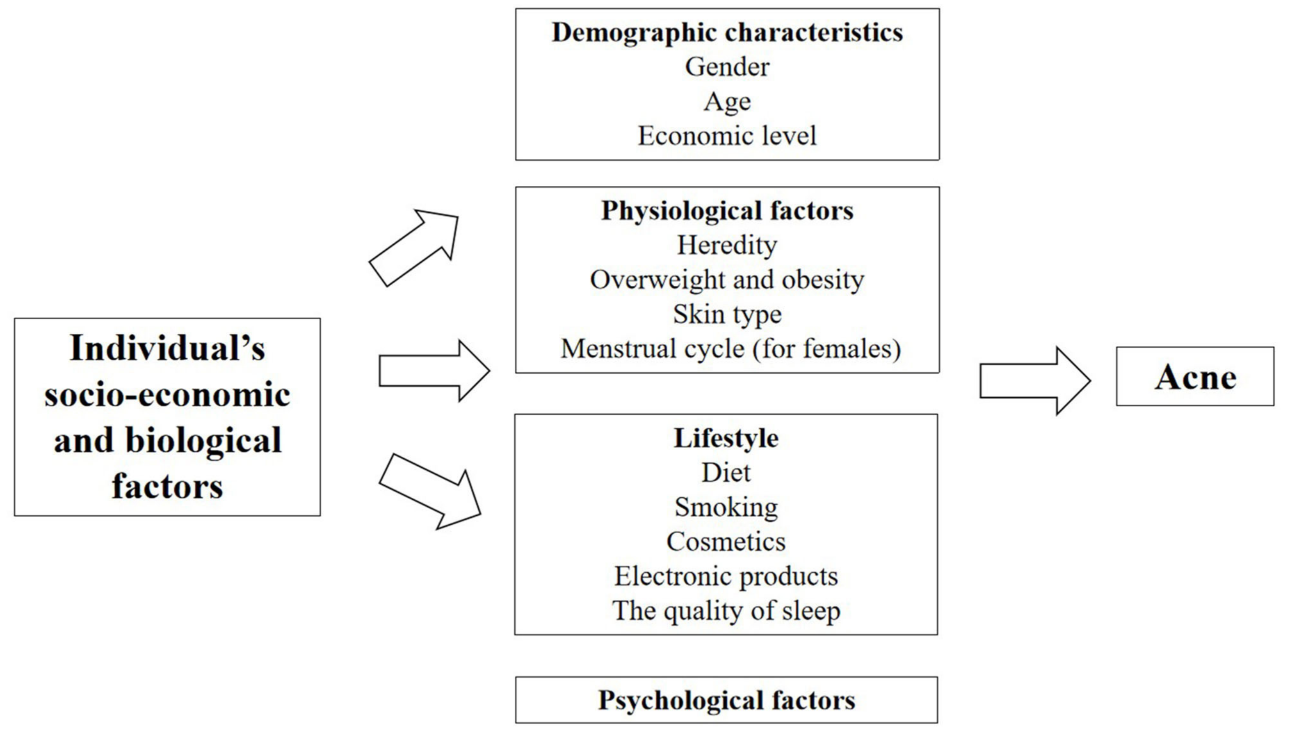

FIGURE 2 | Factors of individual's socio-economic and biological factors affecting acne.

the study had a limitation about the missing information on potential confounders and acne severity. Therefore, the correlation between obesity and acne should be further explored by controlling other influencing factors.

Skin Type

Increased sebum production is key factor with interrelated mechanisms, previous study found the sebum level of face was more in population with acne than without acne (42, 43). Excessive sebum secretion is characterized by oily or mixed skin. In addition, Choi indicated the casual sebum level was positively correlated with the number of acne lesions (44). The epidemiology found oily skin and mixed type skin were risk factors to the acne (21, 25).

Menstrual Cycle (for Females)

Acne in women is frequently associated with hormonal derangement, including hyperandrogenism. Shrestha et al. showed hormonal alteration in females with adult acne had significant association with irregular menstruation (45). Stoll et al. found 44% of women with acne aggravated in premenstrual period (46). Ghodsi et al. also reported the premenstrual phase was recognized as risk factors for moderate to severe acne (30). In addition, Wei et al. indicated dysmenorrhea was a risk factor to the acne suffers (21). Therefore, dermatologists should consider hormonal alterations in acne patients with irregular menstruation.

Diet

The relationship between diet and acne has been a hot topic in the research of acne epidemiology. At present, many studies have confirmed that high sugar diet and dairy products are risk factors for acne (47). Increased sugar intake ($\geq$100 g/d), frequent intake ($\geq$7 times per week) of soft drinks (such as carbonated sodas, sweetened tea drinks and fruit-flavored drinks), and daily consuming dark chocolate were significantly positively associated with acne (30, 48–52). High glycemic load diet can lead to the rise in blood glucose in the body, therefore, islets secrete large amounts of insulin to lower blood glucose, and elevated insulin levels lead to increased secretion of insulin-like growth factors-1 (IGF-1), IGF-1 can increase androgen levels, promote sebum secretion, and promote hyperkeratosis of hair follicle sebaceous glands to affect lipid excretion, thereby inducing or aggravating the occurrence of acne (53–56). And there were studies about a positive association between the incidence of acne and the intake of whole milk and skim milk (57, 58). Milk can also increase the level of IGF-1, which can lead to acne (47, 59–61). In addition, acne can be caused by greasy, fatty foods (62, 63), due to the fact that the release of free fatty acids by triglycerides under the action of P. acnes could promote the development of acne (64). However, it is controversial whether spicy food affects acne. The epidemiological survey of college students in North East China showed that spicy food was a risk factor for acne (21). But other studies have shown that spicy food was not related to the duration or severity of acne (30, 65). Since the two studies did not subdivide the types of spicy foods, the relationship between spicy food and acne needs to be further explored.

Smoking

The relationship between acne and smoking remains controversial. The previous studies found that the prevalence of acne was significantly higher in active smokers than ex-smokers or those who had never smoked (7, 66). And the study have also indicated that in contrast to non-smoking group, smokers had significantly higher levels of inflammatory cytokines (67). However, other studies found that people who smoked regularly showed a significantly lower prevalence of severe acne than non-smokers (22, 68, 69). Therefore, the potential influence and mechanisms between acne and smoking need to be further studied.

Cosmetics

An improper use of cosmetics may cause the recurrence of acne, the study indicated there is a significant positive correlation between frequent exposure to cosmetics and the severity of acne in adolescent women (70). Studies of Latin America and the Iberian Peninsula have shown consistent results (71). Chinese studies also found cosmetic make-up use was a risk factor of acne (25). The reason was because improper skin care practices (such as essential oils or too oily substrates, makeup, excessive cleansing of the skin and soaps with pH 8.0) can modify skin barrier function and skin sebum areas, especially the microbiome balance, thereby activating innate immunity to trigger inflammation (72).

Electronic Products

Visible light emitted by electronic products is a risk factor for acne. Taheri et al. found exposure to short-wavelength visible light emitted from smartphones and tablets could increase the proliferation of Staphylococcus aureus, which could give a rise to an increase incidence of acne (73). Dreno et al. showed people who exposed to screens and tablets before falling asleep were more likely to have acne (28). However, using the computer for $<$2 h a day was considered a protective factor for acne (21).

The Quality of Sleep

Good sleep is essential to good health, poor sleepers [Pittsburg Sleep Quality Index (PSQI) $>$ 5, sleep duration $\leq$ 5 h] had significantly higher levels of trans epidermal water loss (TEWL) than good sleepers (PSQI $\leq$ 5, sleep duration 7–9 h). After tape stripping[3] for 72 h, people with good sleep quality had 30% greater barrier recovery than people with poor sleep. After 24 h of exposure to ultraviolet light, erythema recovery in good sleepers was significantly better (74). When the skin barrier is damaged, the skin's defense system against external stimuli is weakened, which can further lead to skin diseases, especially acne (75). Dreno et al. indicated significantly more individuals with acne than without reported lacking sleep (28). The Chinese study indicate that, sleep duration $<$8 h per day is a risk factor for acne (21). Surveys in South Korea (76) and Japan (77) have consistent results.

[3] Applying tape to disrupt the skin barrier.

Psychological Factors

With the continuous social and economic changes in the contemporary society, the widening of income gap and the increasing stress, the prevalence of mental disorders in China is as high as 9.3% (78). Psychological factors induce the release of neuropeptides and hormones that activate cells to participate in the acne issue (79). The study showed that psychological stress and depression were main risk factors for being acne among college students in the North East China (21). Dreno et al. indicated individuals with acne suffered from significantly higher stress levels than in acne-free individuals (28). Epidemiological surveys in Japan (77), India (80), and South Korea (76) all found that stress was an aggravating factor for the cause of acne.

Natural Environmental Factors

The skin is an important organ that is directly exposed to the external environment. It is also the first barrier against the influence of environmental factors. It protects various tissues and organs in the body from physical, chemical and biological harmful factors. Skin participates in the balance adjustment of the whole body and realize the unification with the external environment. In 2018, Dreno et al. studied the effects of environmental exposure on acne and found that with the changing natural and environmental factors, the response and the susceptibility of body skins to natural environment will accordingly change to a different extent (18). As a consequence of negative impacts on the skin functions, it will increase the occurrence and facilitate the development of acne on people exposed to unfriendly environment (**Figure 3**, Table 2 in **Appendix**).

Temperature and Humidity

Differences in temperature and humidity in different seasons and regions may lead to different prevalence rates of acne. An Indian study found 82 (47.95%) out of 171 acne patients reported seasonal variations in the severity level of acne. It was statistically significant that there were more aggravated acne issues for acne patients in summer (average temperature 32.2°C, average humidity 49.8%) as compared to rainy (average temperature 31.0°C, average humidity 68.5%) and winter season (average temperature 15.1°C, average humidity 79.7%) (81). The study showed that hot weather was risk factors for acne. However, Dreno et al. found there was no significant difference in prevalence of people with or without acne living in temperate or cold regions. Conversely, acne occurrance was significantly more frequent in hot or humid regions (28). Williams et al. indicated sebum excretion rate varied with local temperature, that is, sebum excretion rate increased by 10% for every 1°C increase in temperature (82). A recent study also showed hot environments cause more production of sebum secretion, especially on the forehead (83). Increased sebum excretion might cause acne to worsening. According to a systematic review and meta-analysis, the prevalence rates of acne in the southern China was higher than that of the northern China, because the southern part is more humid and warmer than the north (84). A study also showed that the higher the altitude, the lower the prevalence of acne, which may be related to higher altitudes

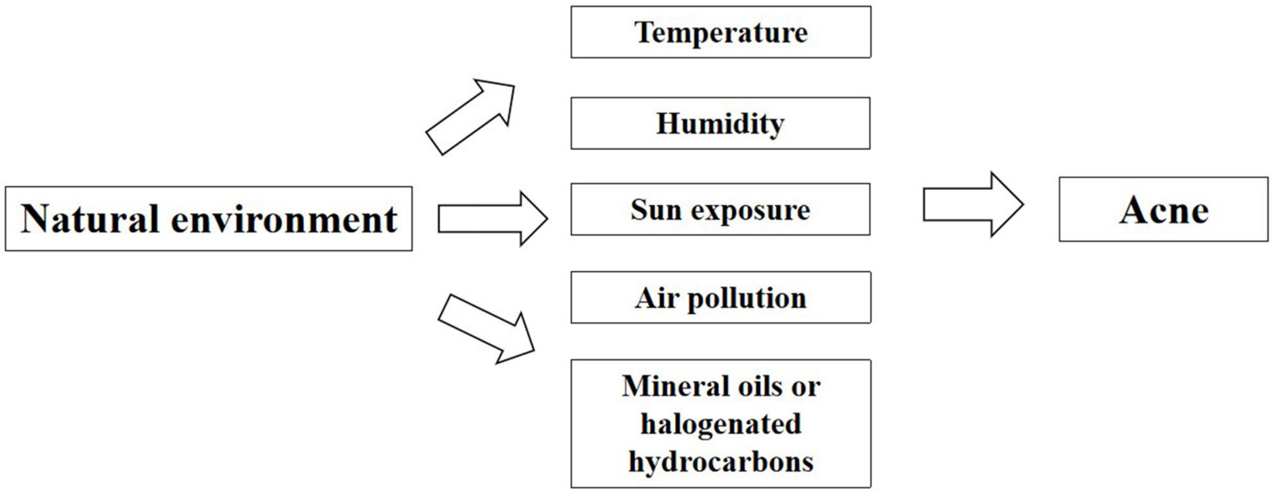

FIGURE 3 | Factors of natural environment affecting acne.

and lower temperature and humidity (85). The above studies indicated that hot weather might aggravate acne, but further quantitative studies are needed on the relationship between humidity and acne.

Sun Exposure

Sun exposure played a significant role in the incidence of acne. A survey of acne patients in India showed that 26.4% of them developed skin lesions after exposure to sunlight and seasonal variation was observed in 44.5% patients exacerbated, because of increased amount of sunshine exposure in summer months (80). Dreno et al. found acne was significantly more frequent in individuals with moderate or intensive sun exposure due to their work or daily activities (28). Lee et al. showed ultraviolet B irradiation increased the expression of inflammatory cytokines in cultured sebocytes (86).

Air Pollution

Air pollution is the most challenging environmental problem for Chinese cities. According to 2016 report on the state of environment in China, only 84 (25%) of the 338 cities have achieved qualified air quality standards for the living of human beings. Over the past decades, people had become more and more concerned about the living condition of urban environment and the health risks related to the increasing and serious air pollution such as$PM_{2.5}$ and PM_{10}. Especially, the relevant negative effects of air pollution on the skins have been the key attention of dermatologists and general physicians (87). Clinical studies reported that air pollutants had a deleterious effect on the skin by increasing oxidative stress, leading to severe change of the normal functions of lipids, deoxyribonucleic acid and/or proteins in the human skin (88). Two clinical studies comparing subjects in the highly polluted areas to ones in the less polluted areas in Shanghai and Mexico discovered that skin quality declined with chronic exposure to ambient air pollution (87, 89). A study in Beijing also indicated that increased concentrations of ambient $PM_{2.5}$, PM10, and NO_2 were positively correlated with numbers of outpatient visits of acne vulgaris over the past 2 years, which further provides an indirect evidence for a link between acne vulgaris and air pollution (90).

Mineral Oils or Halogenated Hydrocarbons

Chloracne is also known as occupational acne, it is a special type of acne caused by exposure to mineral oils or certain halogenated hydrocarbons in production labor (91). The increase of cysts in number is a signal of aggravation of chloracne (92). Dreno et al. found the vast majority of people with acne were significantly more exposed to tar, solvent emanation and crude oil or oil emanation than people without acne (28). Therefore, an effective way to prevent chloracne is to avoid the contact with halogenated hydrocarbons.

Social Environmental Factors

In addition to natural environment, social environment plays a critical role in the health, behavioral norm and social adaptation of the population as a whole (**Figure 4**, Table 3 in **Appendix**).

Social Network

Social network refers to the relatively stable relationship system established by the interaction between different individuals comprising the society, with individuals embedded in the thick webs of social relationships and interactions (93). Recently, there has been much emphasis on the role that social network plays in our physical health, mental health, social behavior and social adaptation (94). According to Cohen-Cole et al. found a friend's acne problems increased an individual's odds of having acne problems (95), which is potentially associated with the similar and interactional living environment, lifestyle and diet among friends. In addition, social networks may have an indirect impact on the occurrence of acne. In recent studies, it has indicated that obesity could spread through various social relationships, which means that the chance of a person developing obesity

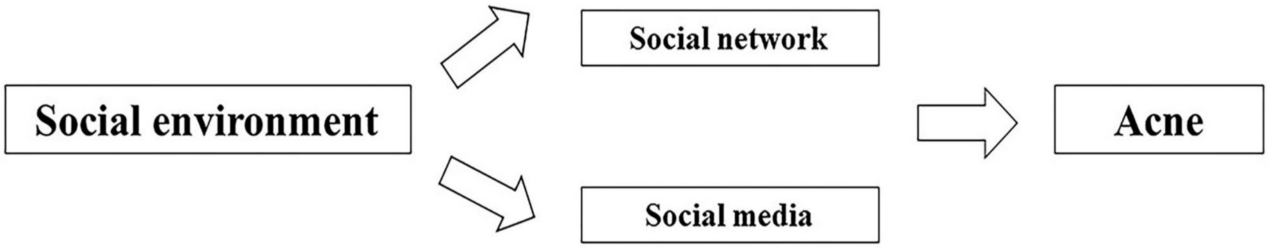

FIGURE 4 | Factors of social environment affecting acne.

increases if his or her friend, sibling or spouse becomes obese, suggesting that people embedded in social networks are subject to the influence from the evident appearance and behaviors of those around them (96, 97). Moreover, there are a growing number of studies demonstrating that social networks could exert impacts on the psychology and behavior, such as depression, anxiety, smoking, drinking and aggression (98–100). In previous studies, obesity, anxiety, depression, and smoking have been identified as the risk factors for acne (21, 28, 37, 66). Therefore, it is possible that social networks have impacts on obesity, anxiety, depression, and smoking among peers, thus impacting on acne indirectly. In this regard, if more studies can be conducted to determine the mechanism of social network behind the occurrence and development of acne, the effective means of behavior intervention can be developed in the future.

Social Media

With the rapid advancement of novel technology, social media has made it convenient for patients to communicate their skin diseases, share treatment and skin care, and even get access to the education on their illness. As revealed by Yousaf et al., 45% of the patients resorted to social media for expert advice on acne treatment (54% of women vs. 31% of men), which evidences the influence of social media on acne treatment. Nevertheless, merely 31% of the participants turning to social media made the changes fully compliant with the American Academy of Dermatology (AAD) clinical guidelines (101). According to Borba et al., the videos of acne education that viewers seek online are clearly inaccurate and poor in quality (102). The incorrect or irregular treatment suggested on social media may contribute to the aggravation of acne. Therefore, the dermatologist appointment on social media is expected to provide the right information to help educate patients.

Built Environmental Factors

The built environment is human-made or modified surroundings, such as buildings, land use (e.g., layout of communities, transportation systems, infrastructures), or green space (12). Research has indicated that built environments and health issues are inextricably linked, because exposure factors affects body condition of human beings (103). Patterns of land development, transportation infrastructure, and building location and design—the built environment could affect the natural environment by replacing natural areas and changing functions and services of ecosystem, which are closely related to the exposure of human beings in the environment.

At present, a growing number of studies have focused on the impact of built environment on health (Table 4 in **Appendix**), especially those chronic diseases such as obesity (13), cardiovascular disease (15) and mental health (14). Studies indicated that obesity was positively associated with population density and the availability of fast-food outlets from the people's residence (104–108). Moreover, other studies also found the incidence of cardiovascular disease was significantly higher with more fast-food outlets than areas with no fast-food outlets (15, 109). On the contrary, compared with cities with less green space, cities with larger or medium green areas had a lower risk of suicide (14, 110). Green plants affect people's psychological function, making them less susceptible to stressful life events, that is, alleviating stress and supporting their reflection on life (111). In addition, the diversity of resources, ease of access, mobility, personal safety, and street connectivity were closely associated with the higher mental well-being scores among the neighborhoods (112). Active transport, including walking, cycling and the use of public transport, delivered health benefits in reducing type 2 diabetes and the mortality due to various causes (113).

All these studies indicated that the built environment played an important role in the incidence of chronic diseases. In the existing research, it has confirmed that built environment exerted some indirect impacts on the health of individuals. Population density, fast food outlets, green spaces and public transport accessibility are exemplified as shown in **Figure 5**. With regard to population density, the potential mechanism lying behind the correlation between residential density and overweight may be associated with sedentary behaviors, as indicated by Xu et al. who demonstrated that the participants in higher-density areas spent more time in sedentary behaviors than those in lower-density areas (114). In terms of fast food, on the one hand, fast food outlets jeopardize the health through high-density fast food restaurants, increasing the chances of eating unhealthy food, frequent fast-food consumption further leads to low nutritional value, excessive sodium intake, increased saturated fat intake, which is linked to cardiovascular disorders, obesity and other metabolic diseases (115–118). While green spaces promote health through four general pathways (119, 120). The first pathway is reducing harm (e.g., reducing exposure to air pollution, noise and heat). With increasing outdoor levels of certain greenspace

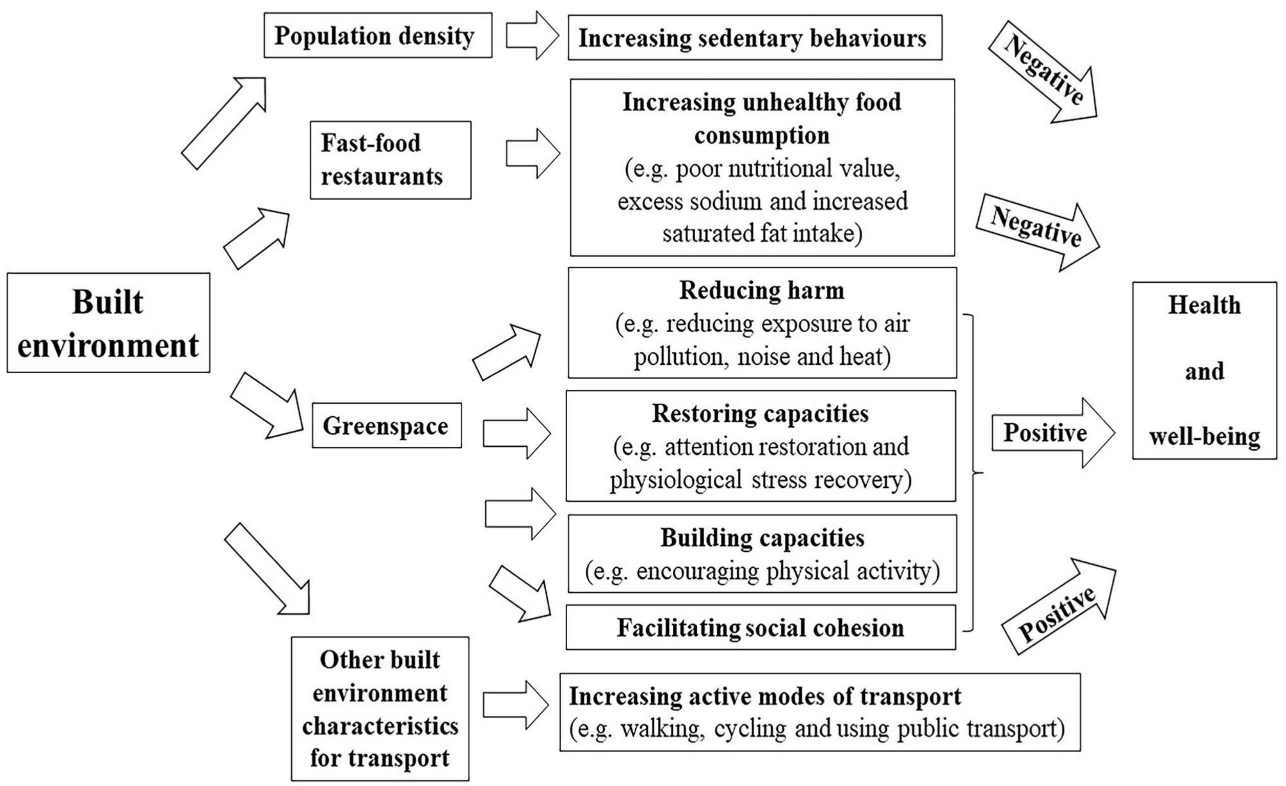

FIGURE 5 | Pathways linking built environment (fast food restaurant and greenspace) to health outcomes (negative: there is a negative effect; positive: there is a positive effect).

indicators, indoor levels of PM2.5 and noise annoyance are reduced (121, 122). The second pathway is restoring capacities (e.g., attention restoration and physiological stress recovery). Viewing plants and other natural environmental features can evoke positive emotions very quickly, thereby shielding negative thoughts and emotions, improving or turning off stress responses (111). The third pathway is building capacities (e.g., encouraging physical activity). Green spaces may provide a safe, accessible and attractive environment for physical activity (123). The fourth way is to promote social cohesion. Green spaces provide an environment for contact with neighbors, which may increase social cohesion within the community (124). In respect of other built environment characteristics for transport, there is evidence that people using public transport are four times more likely to reach the recommended amount of physical activity than ordinary motorists, which is equivalent to an additional 33 min of walking per day (125), moreover, active travel, particularly walking and cycling, has been recommended because of the health benefits associated with increased physical activity (126). Increased physical activity is associated with lower body weight (127).

Skin is one of the main interfaces between human body and external environment and is one of the main barriers to prevent pathogens to invade human body. The main function of the skin is to act as a physical barrier to protect our bodies from potential attack by foreign organisms, toxins, or any other external physical, chemical, or organic factors (128). The built environment may affect the skin through the following mechanisms. Firstly, high population density environment, as a psychosocial stress, induced the impairment of barrier function and water retention property concomitant with decline of ceramide and pyrrolidone carboxylic acid in the stratum corneum (129). Secondly, Yamane et al. suggested high-fat diet reduces the levels of type I tropocollagen and hyaluronan in the skin by inhibiting the effects of transforming growth factor (TGF)-β1, IGF-I and adiponectin, and these effects are harmful for skin function (130). In addition, Meeran et al. showed high-fat diet might increase susceptibility to inflammation-related skin diseases, including the risk of skin cancer (131). So frequent fast-food consumption with high-fat may have a negative impact on the skin. Thirdly, there is increasing evidence that air pollution (e.g., $PM_{2.5}$, PM_{10}, NO_2, SO_2) exerts negative effects on the human skin, it may activate cell metabolism and inflammation (132). Moreover, it has been reported that PM is associated with increased risks of skin diseases, especially skin aging (133), acne (87), atopic dermatitis or eczema (134). Through the above analysis on mechanism, greenspace can reduce exposure to air pollution. Accordingly, the reduction of pollutants is a protective factor for the skin, and the occurrence of skin diseases may also be reduced. Fourthly, psychosocial stress has a negative impact on skin disease by activating the expression of inflammatory cytokines or compromising both permeability barrier homeostasis and stratum corneum integrity (135, 136). Thus, greenspace may protect the skin by reducing psychological stress. Lastly, the study have found high physical activity group showed a positive outcome with respect to wrinkles compared to low and middle physical activity group (137). Therefore, we can guess that greenspace, better public transport accessibility and active travel (e.g., walking and cycling) may be beneficial for reducing wrinkles by providing more space for increasing physical activity.

Acne is a common and chronic inflammatory skin disease, Dreno et al. confirm that internal and external exposome factors had a significant impact on acne (28). Thus, the built environment is closely related to our lives and may also have a potential impact on acne.

DISCUSSION

Building the Indirect Relationship Between the Built Environment and Acne

There is still a lack of scientific research on whether the built environment is related to the occurrence of acne. To bridge this knowledge gap, we will explore the indirect relationship between the built environment and acne, and provide a scientific basis for future epidemiological investigations (**Figure 6**).

Population Density

Population density refers to the average number of people living on land per unit area. According to the study of Tsinghua–Lancet commission on healthy cities in China, between 1978 and 2015, China experienced the largest population migration from rural areas to cities in human history. The urbanization rate increased from 17.9 to 56.1%, and the urban population also increased from 170 to 771 million (1). An epidemiological survey in Asia has found an increase in the prevalence of diseases in areas with high population density (138). Xu et al. indicated residential density was positively associated with being overweight among urban Chinese adolescents (114). High density can increase obesity, which may lead to acne. In addition, an animal study found that high population density in mice damaged skin barrier function and TEWL (129). When the skin barrier was damaged, the skin defense against external exposure was weakened, which could lead to acne (75). However, whether population density affects acne is unknown, the correlation between population density and acne needs further study.

Food Stores

On the one hand, in summary of the factors affecting acne, we found that greasy food, spicy food, dairy products, and sweets are risk factors for acne. So hotpot restaurants and milk tea shops around residents' residences may indirectly affect acne, because a higher number of hotpot restaurants and milk tea shops around the location people work and live, it may be more likely to provide greasy food, spicy food, dairy products, and sweets to people, which could largely increase the possibility of people being acne. On the other hand, obesity is a risk factor for acne, which implies that types and numbers of restaurants around the residential and work location of people could be related to their obesity. A number of studies in the US (139), New York (105), Utah (106), the UK (13, 140), Porto (104), New Orleans (141), and China (142) showed higher fast food restaurant density was significantly associated with higher obesity rates among students. Therefore, an increased number of fast food restaurants near the address may increase the risk of obesity, which may indirectly affect the occurrence of acne. The number of fast food restaurants near the address is one of the measurement indexes of built environment, but whether it affects acne, needs empirical studies to verify.

Green Spaces

Green spaces encourage people to spend more outdoor time for sports, entertainment and social activities. It could have unexpected but important consequences for health in countries with very high levels of ultraviolet (UV) radiation, because sun exposure is one of the risk factors for acne (28). A study in Australia showed that compared to people with 0–20% green space, those with 80% green space had a 9% higher chance for skin cancer. Because people who live near green spaces have higher exposure to outdoor environments and the incidence of skin cancer increases accordingly (143). Different types of green spaces may affect acne, for instance dense trees could reduce UV radiation and therefore protect skin by providing shade, while scattered trees are less protective of skin because they cannot block UV radiation (144). Moreover, there is growing evidence that natural outdoor environments, such as green spaces (i.e., grass, forests, or parks) was increasingly shown to promote mental health. A study in the Netherlands found cities with a large proportion of green space ($>85\%$) or a moderate proportion of green space ($>25\%$ to $\leq 85\%$) had a lower suicide risk than cities with less green space ($\leq 25\%$) (14). Epidemiology research have confirmed that depression and stress are important factors of acne, which means that green space may indirectly affect the occurrence of acne by affecting mental health. According to a study in South Africa, each participant was assigned a value for a green living space, which was obtained from a normalized difference vegetation index (NDVI) generated by a satellite based on the global positioning system (GPS) coordinates of their household location (110). Liu et al. suggested sufficient green infrastructure at the neighborhood scale could protect against depression and promote mental well-being in Chinese urban settings (145–150). Furthermore, green space may be associated with decreased risk of excess weight/obesity (151–153). Therefore, an increase in the proportion of green space near the living and working places may encourage people to participate in more outdoor activities so that decrease the risk of stress, depression and obesity, which may indirectly decrease the occurrence of acne. Green space is one of the measurement indexes of built environment, but its effect on skin, especially acne, needs to be verified by empirical studies.

Other Built Environment Characteristics for Transport

Land-use diversity and street connectivity can influence the choice over transport mode, which in turn affects health (154). In previous studies, it has been demonstrated that a reduction

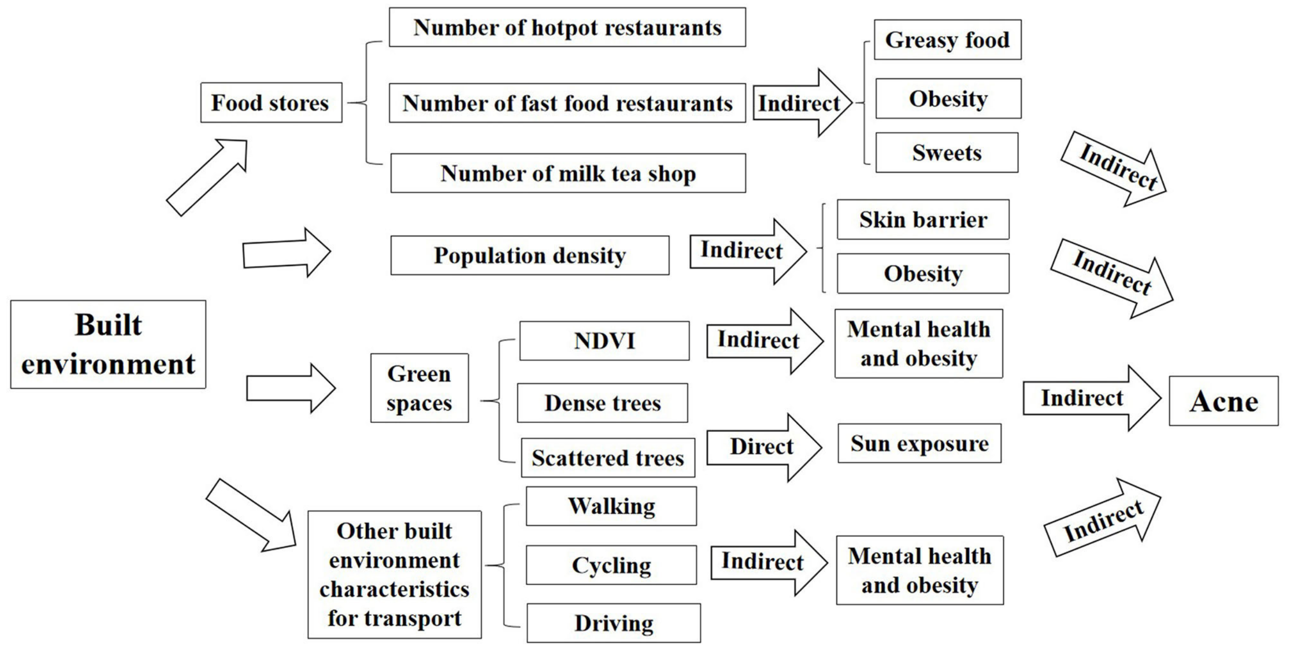

FIGURE 6 | The framework of impacts of built environment on acne (indirect: there is an indirect effect; direct: there is a direct effect).

to the distances to public transport could reduce motorization, which means a modal shift from private motorized vehicles to walking, cycling, and public transport can help improve physical health for all urban residents, for example, reducing obesity, diabetes, cardiovascular disease and respiratory diseases (155–157). Then, the characteristics of built environment for transport may also have impacts on acne indirectly. On the one hand, improving accessibility to public transport will improve population health by promoting the engagement in physical activities (158). A European study was conducted to demonstrate that BMI dropped when people started or increased cycling, but increased when car was used, suggesting the health benefits were created by active mobility (159). Those preferring walking or cycling exhibited a lower BMI over time than those using cars on a long-term basis (160). Additionally, Liao et al. found out that Taiwanese adults mainly reliant on public transport for travel showed a higher likelihood of engagement in transport-related physical activity and a lower level of risk of developing obesity than those who traveled by walking, cycling, or private vehicles (161). On the other hand, different transport modes had different impacts on mental health. Cycling and walking were linked to the positive self-perception about health (162). However, the commute by car has been associated with high stress and lower mental well-being (163, 164). In general, people walking or cycling as a frequent means of commute may have lower BMI and better mental state, which may contribute indirectly to reducing the occurrence of acne, regarding that obesity, psychological stress and depression are the risk factors for acne. Thus, reducing obesity and improving mental health may help reduce the incidence of acne. While the commute by car might produce the opposite result. However, the correlation between the characteristics of built environment for transport and acne may also be influenced by other potential factors, for example, walking without the protection against solar radiation may increase sun exposure, which will aggravate acne as well. Therefore, further research is required to confirm the potential relationship between them.

STRENGTHS AND LIMITATIONS

The core merit of our paper lies in a thorough review of the relevant socio-economic, biological and environmental factors that could impact on acne as well as of the underlying mechanisms. Based on that, the direct and indirect relationships were established between built environmental factors (population density, food stores, social network, transport mode, land use) and acne by reviewing the effects of built environment on health, thus providing a theoretical basis for a further research on the effective means of behavior intervention.

It is essential to acknowledge the weaknesses of the current study, that is, there remain few studies focusing on the impact of built environment on acne. In this situation, attempt was made in our study to determine the indirect relationship between built environment and acne by exploring its impact on obesity and psychology. It was possible to miss some information about the potential confounders impacts on acne.

CONCLUSIONS

Acne refers to a polygenic genetic disorder affected by the interaction between genetic and environmental factors. In this study, it was concluded that acne mostly occurs during adolescence, with age and gender playing a significant role in its occurrence. Besides, the prevalence of acne showed a decreasing trend with age. Males outnumbered females in terms of adolescence acne while it was the opposite in terms of post-adolescence acne. Moreover, acne can be affected negatively by such influencing factors such as family history, overweight, obesity, oily and mixed skin, irregular menstrual cycles, sweet food, greasy food, dairy products, smoking, the improper use of cosmetics, the long-term use of electronics, the poor quality of sleep and stress. In addition, environmental factors play a crucial role, along with various natural environmental factors, including temperature, sun exposure, air pollution, mineral oils and halogenated hydrocarbons, serve as risk factors for acne. Moreover, a further qualitative research is required to figure out the impact of humidity on acne. Lastly, social networks and social media can affect acne as well.

However, the impact of built environment on acne has yet to be reported in previous studies. Thus, an attempt was made in this study to determine the indirect relationships between built environment and acne regarding the impacts of built environment on the risk factors for acne. To cure such a chronic disease, it is necessary to understand the indirect relationship between the built environment and acne by gaining understanding as to the impact of traditional factors on the pathogenesis of acne.

In the future, the study conducted from the perspectives of medicine, sociology of population and geography will be required, and more empirical studies are required to reveal the specific relationship between built environment and acne. The potential built environmental factors for acne ought to be analyzed by collecting the data on demographic characteristics, physiological factors, lifestyle, psychological factors, as well as population density, food stores, green space, climate, pollution status, and so on in relation to the residence of patients with acne, in combination with traditional research factors. In doing so, the impact of built environmental factors on acne can be fully understood to provide specific guidance on reducing the prevalence of acne.

AUTHOR CONTRIBUTIONS

JY, HY, and LH were equally responsible for writing, editing, and literature review. All authors were involved in manuscript preparation, approved the final version, and agreed to be accountable for all aspects of the work.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.00450/full#supplementary-material

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Association Pathways Between Neighborhood Greenspaces and the Physical and Mental Health of Older Adults—A Cross-Sectional Study in Guangzhou, China

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According to the United Nations, the proportion of the older population is increasing at a faster rate than all other age groups. Hence, the well-being of older adults is a mounting concern worldwide in the current century. Using a single greenery metric, previous studies linked greenness to residents' well-being. This study aims to extend this field by focusing on the mental and physical well-being of older adults by using remote sensing and streetscape metrics in evaluating neighborhood greenness. We selected 20 residential neighborhoods in Guangzhou City, China as the cross-sectional case study areas. We investigated neighborhood normalized difference vegetation index (NDVI) collected using remote sensing images, streetscape greenery, and PM2.5 via field surveys. We assessed the health condition of 972 senior residents selected by multi-stage stratified probability proportionate to population size sampling technique (PPS) using a questionnaire survey. We adopted the structural equation model (SEM) in analyzing the pathways that link neighborhood greenness and the mental and physical health of older adults. We found that neighborhood greenness has a positive association with the physical activity by older adults that is positively linked to their physical health. Moreover, neighborhood greenness is positively related to regular social interactions among older adults that is positively linked to their mental health. These findings are consistent with those of previous studies. However, we obtained new results that were unique to China. We found that neighborhood greenness has no significant direct relationship with the physical and mental health of older adults and that social interactions of low-income senior groups are more substantially related to neighborhood greenness than the other groups. Therefore, community planning should emphasize the development of neighborhood greenness, such as parks and street trees, to provide natural spaces for social interactions and places for physical activities among older residents.

Keywords: neighborhood greenspace, physical health, mental health, older adult, structual equation model, Guangzhou

INTRODUCTION

The 21st century is an era characterized by aging and urbanization, and these characteristics are more prominent in developing countries. According to the World Health Organization (WHO), the proportion of seniors (aged 60 years and older) to the global population will reach 22% in 2050 (1). Both the aging rate (Proportion of Population ages 65 and above) (2) and urbanization rate (Proportion of Urban Population) (3) in China, are higher than the global average. Improving the physical and mental health of the older adults in urban areas has become an important issue in China.

Numerous studies conducted in developed countries have demonstrated that greenspace exposure is related to wide-ranging health benefits, including better mental health and physical health (4–15). In terms of mental well-being, exposure of residents to greenspaces may enhance their feelings of happiness and relieve their stress from negative events (16, 17). In terms of physical well-being, exposure to greenspaces has an active role in reducing morbidity from multiple diseases (18–20). Several studies that focused on greenspaces in China explored the relationship between neighborhood environment and residents' well-being (21–25), which reported positive relationship between neighborhood greenspaces and residents' well-being, especially in terms of mental health.

Overall, most studies associating greenspaces and health have been conducted in developed countries. By contrast, other studies in developing countries, such as China, have focused particularly on relationship between greenspaces and residents' mental health using just a single greenness metrics, which could have possibly resulted in biased estimations of indicators (26). In addition, in the face of growing older population, research on the association between neighborhood greenery and older adults' mental and physical well-being is relatively lacking.

This study aimed to address this gap and conducted a cross-sectional empirical research using survey data collected from 20 neighborhoods in Guangzhou City, China, a highly populated city characterized by rapid urbanization and a large proportion of immigrant populations (27), to explore the pathways that link neighborhood greenspaces and older individuals' physical and mental well-being. This study makes the following contributions to knowledge on this topic. First, it focused particularly on older adults in China and used multidimensional survey questions to assess older adults' mental and physical health status to disentangle the aging issues from neighborhood greenspace perspective. Second, both neighborhood normalized difference vegetation index (NDVI) from bird's eye-view and streetscape greenery from human eye-level metrics were measured to quantify neighborhood greenery well. Third, it adopted the multigroup structural equation model in exploring the differences in pathways among older adults with different demographic backgrounds.

LITERATURE REVIEW

The pathway mechanism between greenspaces and health includes direct and mediating pathways that may be different among individuals with different sociodemographic backgrounds.

Numerous studies have revealed the pathway that greenspace exposure directly relates to residents' mental and physical health. In terms of physical health, green in the middle of the color spectrum is more beneficial to human health, especially to the brain and the nervous system than the other colors (28). Moreover, empirical research have shown that natural environments can effectively alleviate headaches by 52% (29). In terms of mental health, visually seeing greenery or green plants alone can help relieve tension and anxiety, and inhaling plants' essential oils can induce changes in psychological state, thereby affecting the psychological stability of the human body (30–33). Given that natural environments are less complicated than urban environments, greenery is conducive in reducing an individual's stress levels and in restoring attention (34–37). These findings have been verified by multiple empirical studies in China (21, 22) and in other developed countries, such as the Netherlands (38) and the United States (39).

In terms of mediating pathways, mediators, such as air pollution, social interactions, and physical activities, also mediate the association between neighborhood greenspaces and residents' well-being. Air pollution, such as nitrogen dioxide, fine particulate matter (such as $PM_{2.5}$), and ozone, has negative health effects, and many studies have demonstrated the negative association between surrounding greenspaces and air pollution (40–42). Greenspaces can help in mitigating urban microclimates and effectively reducing urban environmental pollution and filtering health-threatening air pollutants by sticking wind-blown particulates, such as $PM_{2.5}$ and PM_{10}, to plant leaves and stems (43–45). Meanwhile, long-term exposure to air pollution such as PM2.5 is related to increased all-cause and cardiopulmonary mortality (46, 47), as well as mental disorders (48, 49). An empirical research conducted in Toronto, Canada showed that green roofs on downtown buildings contribute positively to the health of citizens via the air pollution mitigation (50). In summary, greenspaces can effectively improve air quality, and thereby ameliorating residents' health.

The second mediating pathway is via physical activities. Neighborhood greenspaces can be used as a space for physical activities, such as walking, jogging, or cycling, for residents. Greenspaces positively link to individuals' healthy behavior by encouraging them to do physical activities (51, 52). Meanwhile, physical activities benefits health and well-being of individuals from all ages (53). Furthermore, physical exercises performed in greenspaces may produce more health benefits than when done in other environments (54, 55), and limited greenspaces are positively related to sedentary lifestyle, which increases the risks of cardiovascular diseases due to obesity (56). Therefore, the greenspaces could positively link to positive health outcomes via physical exercise.

The third mediating pathway is associated with social interactions. Studies have shown that exposure to greenery may facilitate neighborhood social interactions that may foster the residents' well-being (21, 38, 57). Since greenspace may function as a place for social interactions, it may act as an intermediary variable that links the green environment to residents' health,

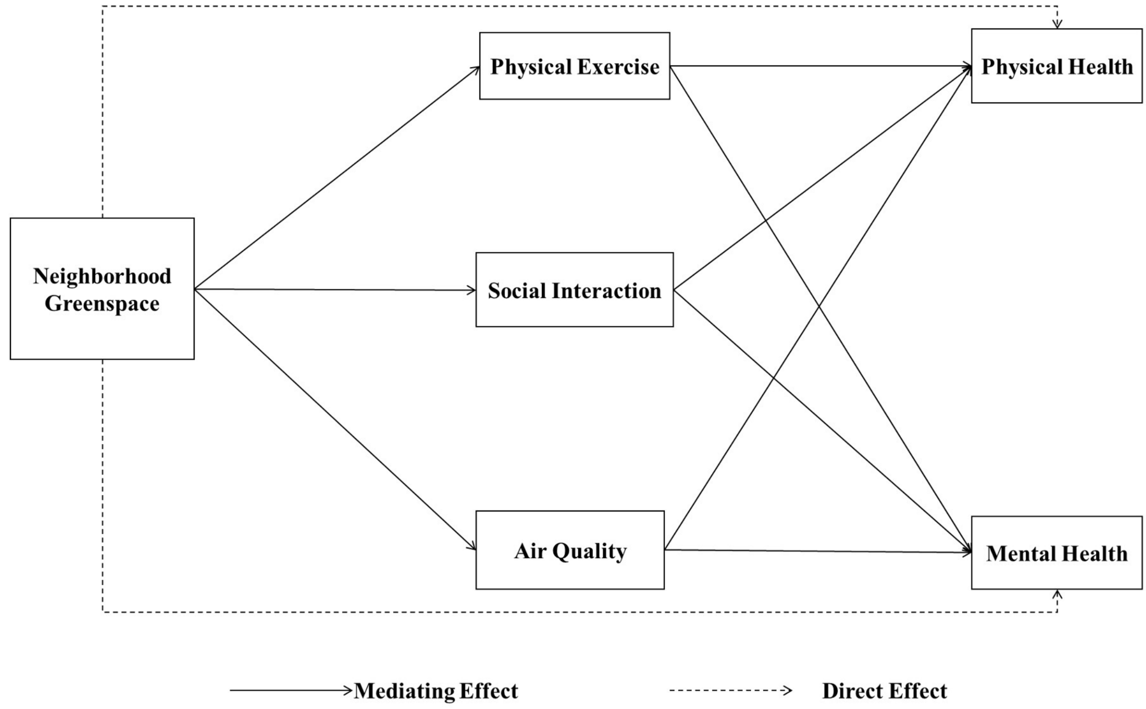

FIGURE 1 | Theoretical pathways of the study.

promote social cohesion by providing a meeting place where people can engage in community activities (58, 59), and help residents obtain social support and reduce feelings of loneliness, thereby reducing stress and fatigue. Such spaces have an indirect positive relationship with mental health (60). Neighborhood greenspaces are particularly essential to aging generation because seniors are generally less mobile and have limited activity spaces and smaller social networks than the other age groups (59). In addition, harmonious social relationships, especially good neighborhood relationships, can promote residents' physical well-being (61, 62).

Based on this literature review, the hypothesis of this study is that neighborhood greenspaces have a direct or indirect linking path with the physical and mental health of the older adults. On the one hand, neighborhood greenspaces directly associate with older adults' physical and mental health. On the other hand, neighborhood greenspaces positively relate to older adults' physical and mental health via neighborhood air quality and older adults' physical exercise and social interaction.

The theoretical structural equation model below was built on the basis of these hypotheses (**Figure 1**).

However, this association between neighborhood greenspace and health may differ among individuals with different socio-demographic characteristics, since they have various opportunities and motivations to access greenspace (60). In terms of income, studies have shown that low-income individuals are more sensitive to greenspace exposure (63), since low-income communities are more likely to have limited access to green spaces (64). As for the age, multiple researches have shown that the health status and health related behaviors of older adults are relatively more related to neighborhood greenspace than other age groups (19, 65, 66), since they tend to spend more time in the communities (67). Regarding gender, since there are gender differences in perceptions and usage of urban green spaces, the health of female individuals are more related to greenspaces than males (68). However, there are few studies focused on the association differences among individuals with different marriage and registered residence status (hukou).

STUDY DESIGN

Data Source and Characteristics

Study Area and Survey Data

A multi-stage stratified probability proportionate to population size sampling technique (PPS) was adopted to select respondents. First, on the basis of the Sixth National Population Census data in China and previous research (69), Guangzhou was divided into six types of social areas of older adults as shown in **Table 1**. Subsequently, 19 streets (jiedao) from these six social areas were selected, focusing on areas with the highest score on factors of interest, and 20 case study neighborhoods were chosen with more than 10% elderly populations (aged 60 and older). The neighborhoods covered six different housing types in Guangzhou City: historic housing, institutional housing, affordable housing, rural self-built housing, commercial housing, and urban village housing (**Table 1**, **Figure 2**). Second, with the number of questionnaires in each neighborhood based on the percentage of its older adults population, a total of 972

TABLE 1 | Geographical characteristics and sample size of the 20 case study neighborhoods.

Social areas of older adults	District	Street (jiedao)	Neighborhood	Housing types	Sample size
Concentrated distribution areas of older adults in old neighborhood	Yuexiu	Zhuguang	Zhujiangyuan	Historic housing	72
	Liwan	Lingnan	Yangrendong	Historic housing	28
		Hualin	Xingxian	Historic housing	28
		Longjing	Huafu	Historic housing	10
Concentrated distribution areas of retired older adults in government agencies, enterprises, and institutions	Liwan	Baihedong	Guangchuanheyuan	Institutional Housing	110
	Haizhu	Nanshitou	Zhibei	Institutional Housing	128
	Tianhe	Yuancun	Meilinhaian	Commercial housing	36
	Huangpu	Huangpu	Huangpuhuayuan	Commercial housing	32
Scattered distribution area of retired elderly in education and scientific research units	Tianhe	Wushan	Huagong	Institutional Housing	94
Concentrated distribution areas of older adults in suburban rural areas in urban setting	Baiyun	Zhongluotan	Dengtang Village	Rural self-built housing	52
			Zhuer Village	Rural self-built housing	35
		Jianggao	Jiang Village	Rural self-built housing	21
	Huadu	Huadong	Shanxia Village	Rural self-built housing	49
Mixed population distribution area	Baiyun	Jinsha	Jinshazhou	Affordable housing	92
	Liwan	Dongjiao	Fanghehuayuan	Affordable housing	22
	Panyu	Luopu	Guang'ao	Commercial housing	23
	Huangpu	Dasha	Hengsha	Urban village housing	32
Concentrated new development areas of younger generation	Tianhe	Tangxia	Tangdehuayuan	Affordable housing	8
	Baiyun	Xinshi	Tangchong	Urban village housing	44
	Panyu	Dashi	Dashan Village	Urban village housing	56

valid questionnaire surveys of randomly selected residents who had lived in Guangzhou for over 6 months and aged 60 and older were conducted by a trained interviewer via face-to-face interview from December 2018 to April 2019. All respondents involved in this study gave their informed consent, and our study has been approved by institutional review board of school of geography and planning, Sun Yat-sen University. The questionnaire covered information on individuals' economic and social attributes, physical and mental health status, physical activity, and social interactions.

Greenspace Data

We acquired streetscape greenery data and NDVI to measure the amount of greenery from street and overhead views in each neighborhood, respectively. The streetscape greenery data were gathered via field surveys in these neighborhoods from March 2019 to April 2019. The data were from obtained from digital photographs taken from sampling points and calculated using the "Maoyanxiangxian" streetscape greenery calculation application. The sampling points were 20 m apart and identified along roads and alleys in and around the neighborhoods from 0, 90, 180, and 270°facing north at a normal view of a human (1.6 m) (70, 71). A total of 2,544 street view images were collected from 636 sampling points.

The satellite-based NDVI (72) of each neighborhood was calculated on the basis of 1,000 m buffer around the boundary of the administrative district of Guangzhou Community Neighborhood Committee and Landsat 8 Operational Land Imager Thermal Infrared Sensor satellite remote sensing image at a 30 × 30 m spatial resolution in October 2017 with only 0.05 cloud cover using Formula 1 from Geospatial Data Cloud (http://www.gscloud.cn) (73). NDVI was calculated as follows:

NDVI = (NIRband5 - Redband4)/ (NIRband5 + Redband4).

Mediators

Data on mediators, including degree of air pollution in each neighborhood physical activity and social interactions, of older adults are were acquired via field surveys and questionnaires.

The level of physical activity of each older adult was determined by the average time spent on physical exercises, such as walking, per day from the questionnaire survey. The unit of measurement was hour.

Social cohesion can be defined in several ways. In this study, we focused on relatively weak social ties of community network. The level of social interaction was determined by asking each senior on what level they agree with the statements that "I know many people in the community" and "I am willing to communicate with community members." The five

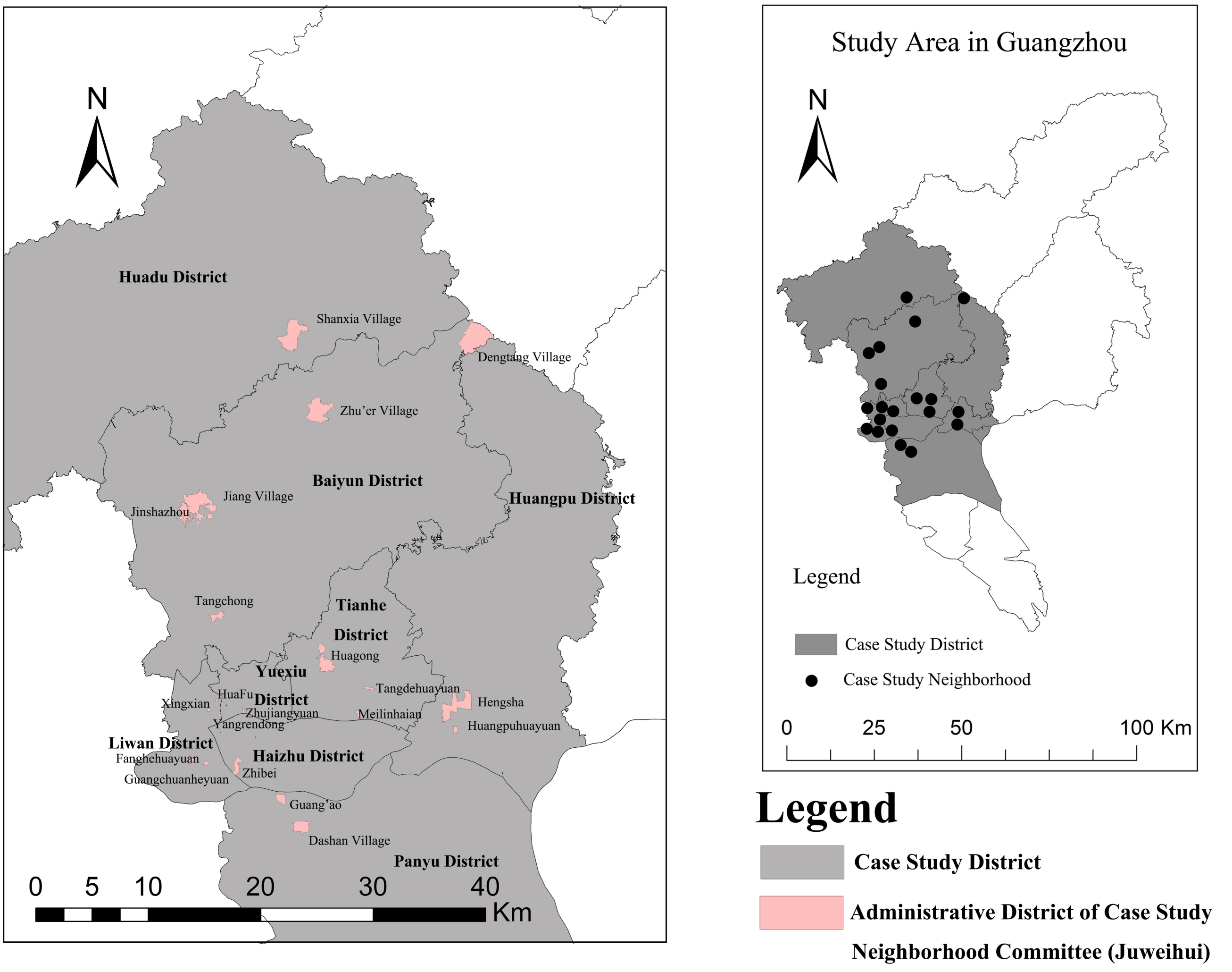

FIGURE 2 | Locations and administrative boundaries of the 20 neighborhoods in Guangzhou City, China sampled in this study.

categories of responses were "Strongly agree," "Agree," "Not decided," "Disagree," and "Strongly Disagree" and coded into 5–1, respectively. The social interaction variable was treated as a latent variable.

We used $PM_{2.5}$ concentrations obtained in each neighborhood to assess the seniors' exposure to air pollution and recorded at the same sampling points with streetscape greenery. The outcome was calculated from the average of $PM_{2.5}$ concentration in each neighborhood.

Analysis Method

Multiple studies explored the pathway between greenery and residents' health by adopting multi-quantitative research methods, such as the structural equation model adopted cross-sectional study (27, 71) and the multilevel linear regression adopted in longitudinal study (5). This present cross-sectional study adopted the structural equation model in Amos 21.0 based on maximum likelihood estimates to test if the theoretical pathways (**Figure 1**) fit the elderly population in Chinese context and explore the pathways between neighborhood greenspaces and older adults' physical and mental health.

To evaluate the reliability of questionnaire data, we conducted reliability analysis on the same type of questionnaire data by using SPSS 21.0. Cronbach's alpha coefficients of social interaction and physical and mental health status as calculated by SPSS were 0.738, 0.912, and 0.939, respectively, indicating that similar questions in the questionnaire had high consistency, good reliability, and substantial research value. In terms of validity, the Kaiser-Meyer-Olkin (KMO) value of the selected data was 0.904 (greater than 0.9) and thus passed the Bartlett sphericity test at the 99.9% confidence level, suggesting that the selected questionnaire data structure had good validity.

RESULTS

Descriptions of the Study Population and Greenery Measures

The characteristics of the neighborhoods and study populations are summarized in **Table 2** without any missing value. Almost half of the respondents were male (43.1%), and 78.1% were young seniors (60–74 years old). About one third (31.9%) of the respondents with the monthly income below 2,100 yuan (according to the minimum wage standard in Guangzhou) belong to low-income group; 77.2% were married, and 69.0% had consistent registered residence status (hukou) with their living address, which means they are local residents.

The median scores for neighborhood streetscape greenery and NDVI were 0.174 and 0.134, respectively. No statistical correlation was observed between these variables ($r = 0.035$, $p = 0.4314$), which justifies using them as two separate observable indicators in the structural equation model (**Figure 3**). The standard deviation (SD) and 25–75 quantile represent variation and the dispersion degree of the data. In terms of mediators, the average time spent on physical exercise of all respondents are about one and half hours, with a standard deviation of 1.056 h, indicating a relatively large variance. The average social interaction score and the median neighborhood $PM_{2.5}$ concentration were 3.806 (SD = 0.790) and 61.690 $\mu g/m^3$ respectively, which is higher than WHO air quality guideline for $PM_{2.5}$ 24-h concentrations (25 $\mu g/m^3$) (74). With regard to health outcomes, the average scores of physical and mental health were 3.421 (SD: 0.855) and 3.950 (SD: 0.754), respectively, indicating relatively good overall health status among the respondents.

Model Modifications and Fit

The RMSEA (Root Mean Square Error of Approximation) value of the initial theoretical structural equation model was exceptionally high. On the basis of the revised index MI and *t* values suggested by the Amos software, modifications of the model were made separately and once a time. The model was analyzed to determine whether the corrections were reasonable by comparing the model fitness index and the Chi-square value before and after the corrections and by ensuring that the model had practical theoretical importance. The modifications involved increasing notable impact paths, such as the impact path between mental and physical health, and deleting observation variables and their paths that do not make a meaningful contribution and remained the loads of the observed variable loading factors of mental and physical health were higher than 0.71. After modifications, the SEM showed a sufficiently good fit to the data: GFI (Goodness-of-fit index) = 0.978 (>0.9) and RMSEA = 0.039 (<0.05). The results and modification are shown in **Table 3** and **Figure 3**.

Model Results

In terms of direct relationships, neighborhood NDVI was not statistically significantly associated with older adults' neither the physical nor mental health at the 95% confidence level. With regard to mediating associations, neighborhood streetscape greenery was positively related to older adults' average time spent on physical activity but negatively related to neighborhood $PM_{2.5}$ concentrations at the 99.9% confidence interval. Neighborhood NDVI was positively related to older adults' social interaction at the 95% confidence interval but negatively related to neighborhood $PM_{2.5}$ concentrations at the 99.9% confidence interval. Older adults' physical activity and level of social interaction were positively associated with their physical and mental health, respectively, at the 99.9% confidence level. Moreover, older adults' mental health was positively related to their physical health at the 99.9% confidence level.

The significant positive association pathways which are consistent with hypothesis includes "streetscape greenery—physical exercise—physical health," "neighborhood NDVI—social interaction—mental health," and the positive association between mental and physical health is newly found. The next step is to analyze the difference of these association pathways among elderly individuals with various socio-demographic characteristics.

Multigroup Analysis

On the basis of the SEM developed above, which is applicable to the entire older adults' group, the less significant ($p > 0.05$) pathways were deleted with only meaningful pathways remained (**Figure 4**). Control variables of different incomes, gender, marital status and registered residence status (hukou) were grouped as the same criteria (**Table 4**) to perform multigroup SEM analysis (Multi-Group Analysis) and further explore differences in the pathways between two corresponding groups.

Four models, namely, unconstrained model, measurement weights restricted model, structural weights restricted model, and measurement residuals restricted model, were calculated and fitted well (GFI > 0.9, RMESA < 0.05). A significant difference ($p < 0.05$) in Chi-square value between the unrestricted and measurement residuals restricted models denotes differences between two corresponding groups. The Chi-square value of the unrestricted and restricted models significantly increased ($p < 0.05$) regarding income, gender, marital status, and registered residence status (hukou), indicating that these variables had a significant regulating effect.

In comparing the pathways between two corresponding groups of significant difference, critical ratios for differences between parameters are used for comparison when both paths are significant. When the critical ratio for difference between parameters was <1.96 (at the 95% confidence interval and higher), the two corresponding pathways were considered equal and vice versa. If one pathway is significant ($p < 0.05$) while the corresponding one is not ($p \geq 0.05$), these pathways are considered different. If two corresponding pathways are considered different in either way mentioned above, they are marked in bold in **Table 4**. In terms of income, the results showed that the level of social interactions of individuals belonging to low-income groups was more strongly associated with neighborhood NDVI, but it had no association with their mental health status. In terms of gender, the physical and mental health of female older adults were more significantly related

TABLE 2 | Summary statistics for all studied variables.

Variables	Proportion/Mean (Standard Deviation)
Population characteristics (total population = 972)	
Gender (%)	
Male	43.1%
Female	56.9%
Age	
60–74 years old	78.1%
=75 years old and above	28.2%
Estimate monthly income (%)	
0–2,100 yuan (low income)	31.9%
2 = 2,100 yuan and above (median or high income)	68.1%
Marital status (%)	
Married	77.2%
Single, divorced or widowed	22.8%
Registered residence status (HUKOU)	
Local registered resident	69.0%
Nonlocal registered resident	31.0%
Predictors	
X1 Neighborhood streetscape greenery median (q25-q75)	0.174 (0.110–0.378)
X2 Neighborhood (NDVI) median (q25-q75)	0.134 (0.108–0.190)
Mediators	
Y1 physical activity(hour)	1.544 (1.056)
Social cohesion	3.806 (0.790)
Y2 I think that I know many people in the community (1–5)	3.708 (0.978)
Y3 I am willing to communicate with community members (1–5)	3.903 (0.777)
Y4 neighborhood PM2.5 median (q25-q75)	61.690 (47.023 – 75.760)
Outcome	
Physical health (1–5)	3.421 (0.855)
Y5 I seem to get sick easier than others (1–5)	3.468 (1.072)
Y6 I have poor health condition (1–5)	3.484 (1.051)
Y7 Feel hard to do heavy exercise activities (such as running, playing, lifting weights, etc.) (1–5)	2.842 (1.221)
Y8 Feel hard to do moderate exercise activities (such as lifting tables, cleaning rooms, doing gymnastics, etc.) (1–5)	3.365 (1.175)
Y9 Feel hard to climb the stairs (1–5)	3.170 (1.228)
Y10 Feel hard to bend and kneel (1–5)	3.295 (1.207)
Y11 Feel hard to walk for about 20 minutes (1–5)	3.670 (1.096)
Y12 Feel hard to bathing and dressing yourself (1–5)	3.997 (0.925)
Y13 Has your body been in pain (such as headache, chest tightness, nausea, etc.) in the past four weeks? (1–5)	3.371 (1.236)
Y14 Has the physical pain affected your work and housework in the past for weeks?(1–5)	3.549 (1.180)
Mental Health (1–5)	3.950 (0.754)
Y15 I feel I am in good mental health status (1–5)	3.985 (0.814)
Y16 I feel calm (1–5)	4.042 (0.803)
Y17 I feel good and happy (1–5)	4.021 (0.875)
Y18 I can concentrate on the things that I am doing (1–5)	3.984 (0.853)
Y19 I don't feel stressed (1–5)	3.880 (1.040)
Y20 I am not nervous (1–5)	3.951 (0.932)
Y21 I don't feel downcast and nothing can cheer me up (1–5)	3.939 (0.922)
Y22 I feel energetic (1–5)	3.797 (0.933)

to average time spent on physical exercise and level of social interaction than that of male elderly. With regard to marital status, the level of social interaction of married older adults showed a significant relationship with neighborhood greenery (at the 99% confidence interval) and significant linkage to mental health (at the 95% confidence interval). By contrast, the social interaction level in unmarried older adults' group showed neither significant association with neighborhood greenery indicators

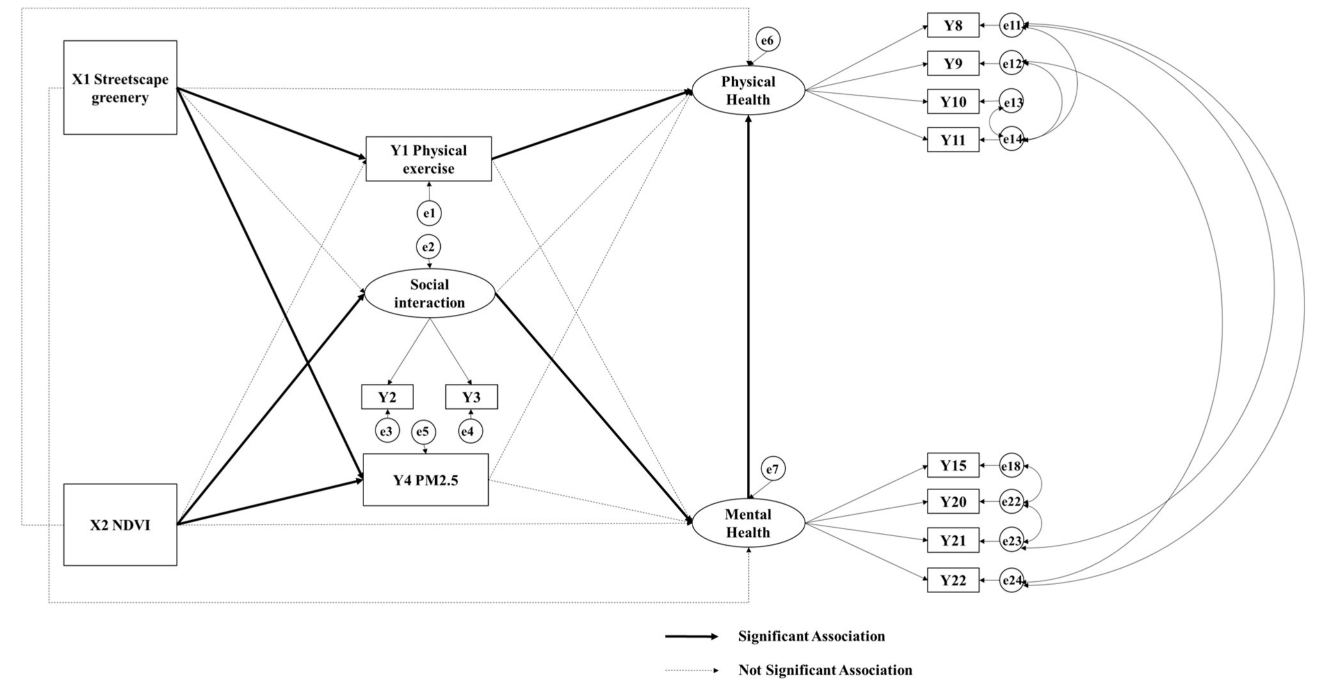

FIGURE 3 | Modified structural equation model and results.

nor exhibited significant association with their mental health. With regard to registered residence status (hukou), the level of social interaction of local groups showed no significant relationship with neighborhood greenery metrics but exhibited significant association with their mental health. Among non-local groups, the level of social interaction was neither significantly positively linked to neighborhood streetscape greenery nor to their mental health.

DISCUSSION

Consistent with previous studies, the present study confirmed that the mediating pathways where neighborhood greenspaces have a positive relationship physical and mental health via physical exercise and social interactions, respectively (55, 60, 75). By adopting the research methods including establishing a theoretical SEM on the basis of the results of previous studies and modifying it accordingly to achieve good model fit. We used the modified model to explore and analyze the internal logical relationships and pathways between greenspaces and the physical and mental health of the older adults in 20 residential neighborhoods in China. We conducted a multigroup analysis to explore whether and how the relationships between neighborhood greenspaces and the well-being of the older adults was different among five control groups. The results of the present study extend the knowledge on this topic in the following aspects. First, this study was the first to systematically investigate the pathways that link neighborhood greenspaces and the physical and mental health of the older adults in a densely populated Chinese city. Second, this study investigated differences in pathways among various control groups of older adults. Third, the study made a methodological contribution by adopting both bird's-eye view NDVI and human-scale streetscape greenery to measure neighborhood greenness.

The Association Between Neighborhood Greenspace and Older Adults' Well-Being

Neighborhood greenspaces are positively related to older adults' physical health via physical activity. Existing research generally agrees that neighborhood greenspaces encourage residents to engage in physical activities (such as walk, run, bike, and other sports) and provide more opportunities for people to exercise, thereby increasing the average time they spend on physical activities (60). Numerous studies conducted in developed countries support the positive association between greenspaces and physical activity among adults (76–78) and children (75). For example, a study in the UK suggested the urban greenspaces are valuable resources to encourage physical activity among children (75). A study in Europe found that large expanses of greenery in residential environments promote more physical activities among adults (77). The present study expands these conclusions to the order residents possibly because they no longer work and spend more time in their neighborhoods. Hence, the association between neighborhood greenspaces with their level of physical activity is more prominent. Older adults who are willing to do physical exercises often participate in morning exercises, group dancing, and other sports in open neighborhood greenspaces, but those who do not participate in such activities still walk around the neighborhood. Trees beside neighborhood lanes provide shade and make their walk enjoyable, thereby promoting physical

TABLE 3 | Standardized estimates and the significance level of modified structural equation model.

Pathways	Standardized estimates	*P*-value
Mediating pathway via physical exercise		
Streetscape greenery → Physical exercise	0.18	***
NDVI → Physical exercise	−0.006	0.054
Physical exercise → Physical health	0.15	***
Physical exercise → Mental health	0.03	0.390
Mediating pathway via social interaction		
NDVI → Social interaction	0.08	0.033*
Streetscape greenery → Social interaction	0.04	0.33
Social interaction → Mental health	0.17	***
Social interaction → Physical health	0.00	0.960
Mediating pathway via PM 2.5		
Streetscape greenery → PM 2.5	−0.39	***
NDVI → PM 2.5	−0.40	***
PM 2.5→ Physical health	0.03	0.853
PM 2.5→ Mental health	0.01	0.831
Direct association		
Streetscape greenery → Physical health	0.00	0.895
Streetscape greenery → Mental health	0.03	0.438
NDVI → Physical health	−0.06	0.053
NDVI → Mental health	−0.04	0.334
New pathway: association between physical health and mental health		
Physical health → Mental health	0.46	***

** Means significant at 95% confidence interval.*
**** Means significant at 99.9% confidence interval.*

exercise. Some suburban seniors still work as farmers, which is also a form of physical exercise. Previous studies also suggested that high levels of physical exercise are associated with good physical and mental health (79, 80). The present study proved this theory in terms of physical health: the longer the older adults exercise frequently has better physical health than those who are mostly sedentary. Studies have shown that physical activities among older adults can preserve muscle mass and reduce age-related decrease in metabolic rate (81), which can potentially result in reducing morbidity and mortality and postponing disability (82). However, the present study found no statistically significant relationships between the elderly's physical activity and their mental health. A possible explanation is that different intensities of physical activity may have a different relationship with older adults' mental health, and intense activity may lead to mood variation and mental deterioration which are more related to the construct of depression (83). However, this study did not consider of the intensity of activity.

Neighborhood greenspaces are positively associated with older adults' mental health via social interactions. Multiple empirical studies in both developed and developing countries have demonstrated that neighborhood greenspaces, as a meeting place for social interactions, have a positive relation to social cohesion (58, 59). Some of these studies were conducted in the Netherlands that covered all age groups above 12 years old (57) and aging populations aged 60 years and older (59). A similar study was conducted in Australia that focused on age groups between 20 and 65 years old (84). Another study was performed in China that concentrated on adults (21). Other works also found a positive relationship between social cohesion and mental health (85) and physical health (62). The present study reaffirmed this pathway to mental health in the context of the older adults in China. In Guangzhou City, most seniors walk together to chat or drink tea almost every day, and the street greenery makes their walks more comfortable, especially during the summer. They meet with friends to acquaint each other in greenspaces where the conditions are cooler. These are places where they play cards and chess. Old tall trees serve as their shade from the sun. The old adults from suburban areas flock in greenspaces to share their experiences at work. Social interactions can positively affect the older adults' perception of their aging status and their own sense of value in their neighborhoods, thereby promoting their mental health (86). Moreover, social interactions can alleviate the older adults' emotional problems through continuous and meaningful interactions with social members. These interactions increase their feelings of positive emotions and thus positively associates with their mental health (87). However, the present study did not find significant linkages between social contacts and physical health among older adults. A possible explanation behind this result is that the definition of social contacts in this study was slightly different from the concept of social cohesion in terms of strength of social ties (88). In addition, social interaction may have detrimental effects, since more interaction may result in more confliction than the counterparts (89).

The hypothesis that neighborhood greenspaces are positively associated with the older adults' physical and mental health by reducing air pollution was not supported because the results showed that neighborhood greenspaces were negatively related to neighborhood $PM_{2.5}$ concentrations, but this parameter exhibited no significant linkage to older adults' physical and mental health. This result contradicted that of several theoretical (10, 90) and empirical studies (71, 91). Especially for older adults, existing studies suggest that PM2.5 concentration is significantly related to their respiratory system (92) and elderly is a susceptible population to $PM_{2.5}$ associated diseases (93–95) and $PM_{2.5}$ related depressive and anxiety symptoms (96). A possible reason for this contradiction is that the association between health and air pollution could only be demonstrated after a relatively long-term exposure (97–99), and certain diseases, including cardiovascular disease, respiratory disease such as asthma, and cancer (92, 100, 101), which takes a while to manifest, while this study is cross-sectional. Moreover, both the mental and physical health status acquired in this study was self-rated. Another possible explanation is that $PM_{2.5}$ concentrations are varying over time. The data obtained in this study only reflected the status of air quality during measurement; thus, the short period of air quality measurement led to bias in data collection.

The present study did not observe strong and significant direct association between neighborhood greenspaces and older

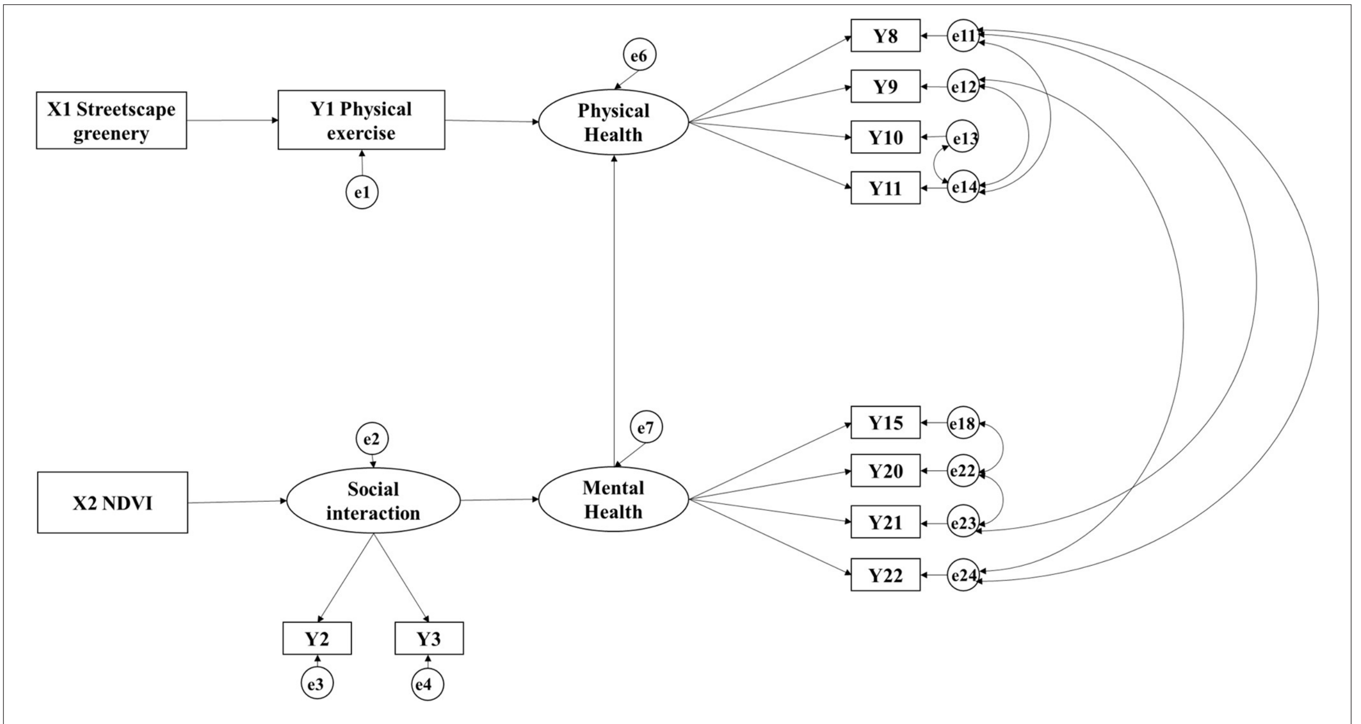

FIGURE 4 | Structural equation model used for multigroup analysis.

TABLE 4 | Standardized estimates and the significance level of unconstrained model of multigroup analyses.

Group	Pathway	Streetscape greenery→ Physical exercise	Physical exercise→ Physical health	NDVI→ Social interaction	Social interaction→ Mental health	Mental health→ Physical health
Estimate Monthly income	0-2100yuan	0.16**	0.17**	**0.16*** **	**0.01**	0.38***
	2100 and above (medium and high income)	0.20***	0.14***	**0.04**	**0.17** **	0.47***
Gender	Male	0.19***	**0.08**	**0.24*** **	**0.11**	0.50***
	Female	0.20***	**0.20*** **	**−0.08**	**0.21** **	0.43***
Marital status	Married	0.16***	0.14***	**0.13** **	**0.12* **	0.49***
	Single, divorced or widowed	0.29***	0.19**	**-0.06**	**0.19**	0.35***
Registered residence status (Hukou)	Local registered resident:	0.12**	0.16***	0.04	**0.18*** **	0.44***
	Non-local registered resident	0.23***	0.14**	0.07	**0.1**	0.50***

** Means significant at 95% confidence interval.*

*** Means significant at 99% confidence interval.*

**** Means significant at 99.9% confidence interval.*

Bold means the corresponding pathways are considered significantly different.

adults' well-being. This result contradicted that of previous studies (21). According to the literature, neighborhood greenery is positively related to an individual's physical (102, 103) and mental health (21). A possible reason behind this inconsistency is that the association between short-term effects of exposure to greenspaces and long-term physical and mental health of older adults is not significant. Most existing studies focused on the association between greenspaces and a specific health aspect instead of overall health status. For example, a study that examined short-term changes in vascular risk factors found a positive relationship between urban green environments and health (102). This cross-sectional study had a smaller scope and encompassed a shorter time period. Another possible explanation is that not all plants can have beneficial effects on residents' health, and some plants that are toxic, attract insects, or easily become allergens actually have negative effects on their residents (104).

An unexpected result was obtained by the present study: the mental health of older adults was positively associated with their physical health. An empirical study in Australia showed that positive attitudes to aging are associated with positive self-reported physical health status (105). Older adults with strong mental health status and positive self-recognition are more likely to have excellent physical health.

The Association Pathway Among Older Adults With Different Sociodemographic Characteristics

We performed a multigroup analysis to explore the differences among older adults with different sociodemographic characteristics. Overall, the "neighborhood greenspace—physical exercise—physical health" pathway is significant in all older adults' group except male group. While the "neighborhood greenspace—social interaction—mental health" pathway is dramatically different among the corresponding groups. The level of social interaction of individuals belonging to low-income group was more significantly associated with neighborhood greenspaces probably because of limited expendable funds they have to pay for social activities outside their neighborhoods and unfamiliarity to their external environment, indicating that they are more dependent on freely accessible neighborhood greenspaces. However, the social interaction parameter was not significantly associated with their mental health status probably results from social exclusion due to their disadvantaged social status. As for female older adults, their mental and physical health are more significantly associated with social interaction physical exercise, respectively, than those of male elderly. While the social interaction level of the male group is more significantly linked to the neighborhood NDVI than the female group, probably because most male older adults communicate with friends within the neighborhood greenspace than female. With regard to unmarried elderly, the association of neighborhood green spaces on their level of social interaction was not significant because their interactions with close friends is not necessarily limited to neighborhood greenspaces and they tend to have more freedom to go outside the neighborhood. In terms of registered residency status, the level of social interaction of the non-local groups was neither significantly related to neighborhood greenery nor to their mental health. A possible explanation is that the social network of these non-local older adults remains in their former residence, and the neighborhood network here seems foreign to them. In general, older adults, especially those who belong to low-income group, have limited spaces for activities and socializing that is why they are more dependent on neighborhood greenspaces, a supposition consistent with that of previous studies (106, 107).

Strengths and Limitations

The present study was one of the first to examine the association pathways between neighborhood greenspaces and older adults' physical and mental health in a Chinese city. This study has two main strengths. First, we adopted two metrics of neighborhood greenery, namely, bird's-eye view and human view, to minimize statistical bias. Second, we concentrated on older adults with different sociodemographic characteristics to identify differences among groups and focus on vulnerable groups.

This study has several limitations that must be addressed in a future work. First, it is a study based on cross-sectional data and research design, which may overestimate the association make it difficult to infer causation between neighborhood greenspace and older adults' well-being. Second, streetscape and $PM_{2.5}$ data were collected via field surveys and with relatively limited sample sizes. Hence, the data may lack accuracy. Other data acquisition methods, such as calculating the average annual air pollution concentration from secondary data sources (71), extracting street view images from maps (27, 70) and focusing on the respiratory morbidity of older adults, may improve the accuracy and find meaningful result. Third, the health outcomes were determined from subjective questionnaire surveys. Objective health outcomes, such as BMI and morbidity, may be more reliable. Moreover, the greenspace accessibility analysis as well as the association pathways analysis among communities with different housing nature could be also taken into consideration in the future research with larger sample size.

CONCLUSIONS AND RECOMMENDATIONS

On the basis of review of literature on greenspaces and residents' well-being, we constructed an SEM linking neighborhood greenspaces and older adults' physical and mental health status. We obtained primary data from 972 urban and rural elderly populations and streetscape greenery and $PM_{2.5}$ concentration data from field surveys of 20 residential neighborhoods in Guangzhou City from 2018 to 2019. We also gathered secondary data from neighborhood committee level NDVI data from 2017 Landsat image. We found that neighborhood greenspaces have a positive relationship with older adults' physical exercise, thereby positively associates with their physical health. Moreover, greenspaces have a positive linkage with older adults' social interaction. Thus, greenspaces are positively associated with their mental health. These findings are consistent with those of previous studies. However, we found that neighborhood greenspaces have no significant direct association with older adults' physical and mental health. Furthermore, we found that the level of social interaction is more significantly related to neighborhood greenspaces among low-income groups, and mental health is more significantly linked to the level of social interaction among local and unmarried groups. Based on the findings, we suggest that urban planners should design neighborhood greenspaces where the older adults can exercise and communicate with each other. They can also plant trees along sidewalks to provide desirable walking environment for seniors, and recreational infrastructures under shaded trees to increase community interactions among the older adults. Finally, they can develop greenspaces in communities with a high proportion of vulnerable elderly, especially for those that belong to low-income groups.

DATA AVAILABILITY STATEMENT

The datasets presented in this article are not readily available because of institutional copyright issues. Requests to access the datasets should be directed to Yuan Yuan, yuanyuan@mail.sysu.edu.cn.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by School of Geography and Planning, Sun Yat-sen University. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

YY contributed to the conception and design of the study and is in charge of the project. YZ, YC, and SL contributed to data preparation, collection, and organization. YZ performed the statistical analysis, structured, and wrote the first draft of the manuscript. YY, YZ, and YC contributed to manuscript revision. All authors read and approved the submitted version.

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Disparity in Perceptions of Social Values for Ecosystem Services of Urban Green Space: A Case Study in the East Lake Scenic Area, Wuhan

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Urban green space can bring various ecosystem benefits to diverse social groups. Among those ecosystem benefits, intangible social values are often neglected but highly relevant to human welfare. Existing research on the social values of urban green space often focusses on the perspective of urban inhabitants rather than tourists, even though tourists are also major beneficiaries. By combining different data sources into a comprehensive source about green-space social values, we investigated the disparity between inhabitants' and tourists' perceptions about space-associated social values, and further explored the underlying environmental conditions in the East Lake scenic area, Wuhan. For this, we collected 347 questionnaires through an on-site survey and 11,908 photos uploaded by 2165 social media users (Sina Blog), and we used SolVES (Social Value for Ecosystem Services) to uncover the spatial patterns of social values and the relationships between social value indicators and natural surroundings. Social-value hotspots occurred near water and trails. Perceptions differed, however, between inhabitants and tourists. Inhabitants perceived a larger scale of social values and could benefit more from recreation and economic values. Tourists, on the other hand, showed greater appreciation for aesthetic and cultural values. Environmental features were associated with social values to differing extent; distance to water and land use/cover exerted significantly influence. These findings should be taken into consideration to improve urban spatial planning and to optimize green infrastructures for human welfare.

Keywords: social value, ecosystem service, urban green space, SolVES, environmental conditions

INTRODUCTION

Urban green space (UGS), as public and private open spaces in urban areas (1), can provide multiple kinds of service: water regulation, pollution reduction (2), noise alleviation (3), carbon storage (4), provision of habitat, and opportunities for cultural services (5). However, intangible and non-material benefits of UGS have received less attention in past research (6–8). Increasing evidence shows that the social values of ecosystem services could strengthen links between humanity and nature (9–12).

Research on subjective perceptions of UGS will provide a better understanding of the quality and quantity of urban green spaces (13, 14), as well as ecosystem services. Cultural ecosystem services provide the critical role of UGS from the perspective of users, and thus offer a promising way to integrate citizens' perceptions into urban planning (15, 16). Investigation of a pooled sample may inform policy makers by integrating perspectives and thus avoid interpretative difficulties due to stakeholder heterogeneity.

While it would be possible to examine the whole group at once, stratification of stakeholders delivers more detailed information about diverse interests (17); surfacing the diversity of perceptions can increase public managers' awareness of how different benefits are felt by different groups of people (18, 19). The groups are often distinguished by features such as familiarity with green infrastructure (20), gender and age (21), religion (7). Moreover, the spatial dimension of ecosystem service benefits is particularly important when considering important stakeholder groups (22). Existing research indicates that urban residents and visiting tourists conflict in their preferences over congestion, environmental protection, and employment opportunities (23, 24), and their knowledge of the area (25). An especially clear stratification of residents and tourists is hence found in coastal regions, forests (26) and national parks (27). As for UGS, previous research has focused mainly on benefits for the local residents who directly and perpetually benefit, and on investigating the market value for tourist and resident visitation (28–30). However, tourists' travel costs and familiarity differ markedly from urban residents' (31). Therefore, a systematic analysis has been employed to incorporate the residents' perspectives with tourists' perspective to investigate the social values of UGS by investigating how residents and tourists perceived non-material value in combination with inherent environment features.

Understanding the stakeholder perception involved a public participatory geographic information system (PPGIS) (9, 32, 33). PPGIS use is becoming increasingly widespread across ecosystem service assessment because the map makes information explicit, visualizable, and informative to urban planners during the decision process and during management of urban green spaces (34). Question-based and photo-based data are the main data sources for mapping and evaluating ecosystem services. Question-based data collection was obtained from face-to-face, telephone interview and on-line questionnaire interviewing (35, 36). Questionnaire responses directly reflect the perspective of different stakeholders at a specific time point. However, the questionnaire is inadequate for telling the whole story over a time period. Geo-tagged photos from employed visitors and social media compose photo-based data sources. Visitor-employed photography (VEP) can provide visitor trajectories, but are constrained by time consumption, expense and the spatial scale (37, 38). Social media platforms such as Flickr, Sina Blog, and Instagram can provide a large quantity of time series data at a lower cost than traditional surveys (39–41). Relevant studies focus on spatial and temporal trade-offs of ecosystem services (42), the impact of landscape change on ecosystem services (43), and human benefits under various scenarios (12). In particular, Sina Blog had as many as 550 million monthly active users in March 2020 (http://ir.weibo.com/), and is one of the most popular social media platforms in China. Until now, little work has been done coupling the questionnaires with social media. Integrative data sources across documenting users' experiences of green space over periods of time might offer interesting, new prospects for urban green space design and management.

TABLE 1 | Typology applied in on-site survey and classification of Sina Blog photos.

Social value indicators	Value descriptions
Aesthetic	I enjoy the beautiful scenery, sights, delightful sounds, etc.
Biodiversity	It provides a variety of fish, wildlife, plant life, etc.
Cultural	It is a place for me to continue and pass down the wisdom and traditions, participate various cultural activities.
Economic	It provides timber, fisheries, minerals, and/or tourism opportunities such as outfitting and guiding.
Future	It allows future generations to know and experience tradition, lifestyle right as them are now.
Historic	It has architectures and stories of natural and human history that matter to me, others, or the nation.
Intrinsic	I value it in and of itself, whether people are present or not.
Learning	We can learn about the environment through scientific observation or experimentation.
Life Sustaining	It is the habitat of creatures and helps preserve, clean, and renew air, soil, and water.
Recreation	It provides a place for my favorite outdoor recreation activities.
Spiritual	It is a special place to me or because I feel reverence and relaxation here.
Therapeutic	It provides a wonderful place for exercising and makes me feel stress free, physically and/or mentally.

Adapted from Sherrouse et al. (49).

Mapping of UGS services can be informative for urban planning and sustainable development (44). Less is known, however, about how to characterize and represent non-material values of ecosystem services in decision-making. Social values offer one way to evaluate the subjective, intangible services, especially for cultural services (45, 46). Social values originated from the evaluation of forest values (47). The individual value indicators composing the social-value typology (**Table 1**) provide the foundation for understanding the preferences of different stakeholder groups. Social Values of Ecosystem Services (SolVES), a GIS application from the United States Geological Survey (USGS), is based on that typology and has been proved useful for evaluating ecosystem services, trade-offs between value indicators, and social value of regions where data are unavailable (48–51). SolVES quantifies the relationships between social values, people's perceptions, and environmental conditions. By considering both the ecological and social contexts of values referring to ecosystem services, valuation results can be made meaningful for the spatial allocation of relevant ecosystem services and day-to-day decision making.

This paper investigates the spatial pattern of social values and examines the relationship between perceived social values and environmental conditions at the East Lake Scenic Area. Residents and tourists are the main stakeholders as mentioned above. Questionnaire and social media data were analyzed using SolVES to address three objectives: (1) discern the spatial pattern of perceived social values; (2) compare the social value indicators between two stakeholder groups; (3) identify relationships between preferable social values and environmental conditions. The paper aims to create space for discourse on the social values of urban green area and enlighten thought about how the perceptions of different visitor groups can be more effectively integrated into urban planning and green space management decisions.

METHODS

Study Area

Wuhan (113.68–115.08E, 29.96–31.36N) is the transport and economic center of central China and the capital of Hubei Province, with a total area of 856,915 ha and a population of 108.93 million (52). The climate is subtropical monsoon, with an average temperature of 16°C and average precipitation of 1,200 mm. Rivers and lakes are the characteristic ecosystems of the area. The Chang Jiang (which becomes the Yangzi River downstream) and the Hanshui (the Yangzi's longest tributary) cross the city. The second largest inner-city lake in China is located in the East Lake (Dong Hu) scenic area (ELSA, 1320 ha), which is the well-known "National 5A-class tourist attraction." Owing to its unique and essential location, the East Lake provides habitat suitable for over 500 species of flora and fauna. From 2000 to 2020, the government has proposed and implemented policies to improve the green elements of Wuhan (53). Notably, the urban greenway construction around the East Lake, with a total length of 101.98 km, connects eight parts of the ELSA: Mo mountain, Tingtao, Luoyan, Chuidi, Baima, Hou lake, Yuguang, and Yujia mountain. It significantly improves the environment and draws attention to its characteristics. Overall, 23 million visitors arrived in the ELSA in 2019, with an increase of 15.12% than the last year (54). Visitor expense in the ELSA contributes to local economies and supports human well-being by providing recreational opportunities, and promotes environmental stewardship. The ELSA demonstrates a good balance of ecological protection and financial benefit.

Data Source

The collection of data comprised two phases: an on-site survey, and collection from social media. The on-site survey included both a pilot survey and a formal survey. The pilot survey (n = 20, response rate 100%) was conducted in December, 2018 to validate the questionnaire. The formal survey was collected from a representative sample of people over the age of 14 who visited ELSA during a high-use vacation period (Labor Day, May 1–4) in 2019 (n = 370, response rate 93.78%). While the visitors relaxed in the Scenic Area, they were approached by proficient survey administrators and asked to express their own opinions. The sampling frame was stratified by time of day to ensure that sampling events were not biased by daily schedules.

The questionnaire was divided into three parts. Part (1) addressed recreational characteristics and visitor experience. It asked about attitudes toward eleven kinds of activities such as hiking, riding a bicycle, walking, blossom appreciation.... Part (2) addressed value allocation and mapping. The interviewers and respondents engaged in an interactive mapping exercise that entailed visitors to allocate 100 CNY to reflect the importance that they ascribed to each of the 12 social values for the ecosystem services listed in a typology (**Table 1**), introduced from past research and pre-survey. Following the allocation of preference value points, respondents were asked to identify representative scenic points that embodied the values to which preference points were assigned, using a map of the ELSA created from Google Earth (55). The map of ELSA had a scale of 1:5 km (screen to terrain) and served as a visual basis for communication with respondents. The points marked by respondents were recorded on digital maps for later analysis. Part (3) of the questionnaire asked about visitors' background characteristics. Items concerned gender, occupation, visiting frequency, what attracted them to ELSA. People who reported residence in Wuhan were classified as "residents"; otherwise as "tourists."

Another data source was Sina Blog, an important platform for people sharing text posts or photos about sightseeing and opinions. Sina Blog has proven to provide an accessible and effective data source (56, 57). It can provide succinct and public geotagged text, link, photo or video content about landscapes that can then be analyzed spatially and quantitatively. Focusing on the ELSA scenic spots identified during the questionnaire phase, we collected 2519 posts about the ELSA from the Sina Blog website across the whole year 2019. Each post includes the main text body and photographs, and the writer's residence and gender. Whether the main body and photos are about the ELSA scenic spots was applied as a sifting condition. Finally, 2165 blog posts for further analysis contained a relevant text description, and there were around 5.5 photos per post on average. The combination of social media and questionnaire were anticipated to provide an interesting perspective on the differences between value preference among residents and tourists, over a meaningful time span.

Data Processing

Social media photos contain landscape features like lake, trees, greenway, and cherry blossoms, providing considerable information that could help to identify the locations and relevant social value indicators. Adding to the points from the on-site survey, all preferred points allocated to each social value were entered into an ArcGIS geodatabase as a point feature class (n = 9971). Without the opportunity to record Sina blog users' perspectives on value allocation, we calculated the average value allocation amount of each social value indicator in the on-site survey, making separate calculations for residents vs. tourists. Specifically, we calculated the average number of points for each value indicator allocated by residents and tourists in the questionnaire phase (**Table 2**), then applied those calculations when assigning values for the social media data. For example, for a blog from a tourist about Ma'an Mountain Park related to biodiversity, intrinsic, future values, the allocation of each value will be 13.09, 3.53, 8.78 CNY. If this same blog post came from a resident, the values assigned would have been 13.01, 3.55, and 7.14 CNY.

TABLE 2 | Statistics of social value for residents and tourists.

Social value indicators	Residents					Tourists				
	N_COUNT	R_RATIO	Z_SCORE	MAX-VI	Average allocation (CNY)	N_COUNT	R_RATIO	Z_SCORE	MAX-VI	Average allocation (CNY)
Aesthetic	429	0.19	−32.16	8	13.39	1,065	0.13	−54.48	9	12.44
Biodiversity	218	0.22	−22.09	3	13.01	275	0.27	−23.21	1	13.09
Cultural	332	0.13	−30.17	8	13.16	994	0.08	−55.43	10	15.38
Economic	441	1.00	−36.16	8	4.14	705	0.13	−44.18	4	3.53
Future	345	0.21	−28.14	7	7.15	932	0.12	−51.39	7	8.78
Historic	281	0.10	−28.80	7	9.56	917	0.07	−53.95	7	10.52
Intrinsic	190	0.24	−20.16	2	3.55	238	0.15	−25.05	1	3.53
Learning	247	0.16	−25.26	5	6.36	858	0.08	−51.48	5	4.89
Life Sustaining	238	0.18	−24.14	3	12.19	301	0.20	−26.57	1	11.17
Recreation	542	0.14	−38.43	10	5.79	909	0.12	−50.85	6	6.41
Spiritual	217	0.20	−22.46	2	8.04	295	0.19	−26.60	1	6.12
Therapeutic	116	0.21	−16.23	1	3.66	159	0.28	−17.44	1	4.14

Number of mapped points (N_COUNT), results of average Nearest Neighborhood statistics (R_RATIO and Z_SCORE), maximum Value Index scores (MAX_VI), average value allocation of on-site survey.
Color values represent the magnitude of Value Index, the darker the color, the higher the Value Index, vice versa.

TABLE 3 | Description of environmental layers and data source.

Environmental layers	Description	Source
Distance to road	Horizontal distance to the nearest road in meters	Deprived from open street map using ArcGIS Euclidean distance tool https://www.openstreetmap.org
Distance to water	Horizontal distance to lake in meters	Deprived from open street map using ArcGIS Euclidean distance tool https://www.openstreetmap.org
Elevation	Digital elevation model (DEM) in meters	NASA Earth data http://vertex.daac.asf.alaska.edu
Land cover	7-class categorical land cover data	Deprived from ZY-3 (5.8 m) remote sensing images

The geodatabase built for the SolVES process included five environmental characteristics with potential to explain spatial variations in social value intensity (**Table 3**). The first three environmental characteristics were distance to features relevant to visitor choice in the ELSA, specifically road, water, and elevation. These distances, created using tools available in the Spatial Analyst extension of ArcGIS, reflected the shortest straight-line distance of each cell to features of interest. Next, land use/cover raster data interpreted from ZY-3 (resolution is 5.8 m) was used to represent the natural conditions. Resampling and conversion tools helped to coordinate all of the raster layers at the same resolution (10 m) and extent. Besides, the questionnaire data distributions were tested for normality using the Shapiro–Wilk test in R, version 4.0.0. Data processing also made use of Python 3.8, EXCEL 2019 and ArcGIS 10.5.

Analysis of Social Value Indicators and Environmental Layers

We identified relationships between mapped social value points and four environmental characteristic layers for both residents and tourists using a GIS mapping application developed by the U.S. Geological Survey (58), Social Values for Ecosystem Services (SolVES 3.0, http://solves.cr.usgs.gov). The composite maps showed social values using a Value Index ranging from 0 (least important) to 10 (most important). We also applied SolVES to create a measure of the density of point features using the Completely Spatially Random (CSR) hypothesis test, which is based on and averages nearest-neighbor statistics. The value R represents the ratio of observed distance between points to the expected distance between them; the Z score measures how many standard deviations the point is from the mean, and is helpful for determining whether point patterns are dispersing, clustering or random. The weighted kernel density surfaces were generated from the total preference points allocated to each value indicator. All of the surfaces were standardized and normalized to determine the relative importance of each social value (**Figure 1**).

The Maximum Entropy calculator, MaxEnt, within SolVES generates a logistic surface layer, providing potential locations to which stakeholders can allocate social value. The logistic surfaces

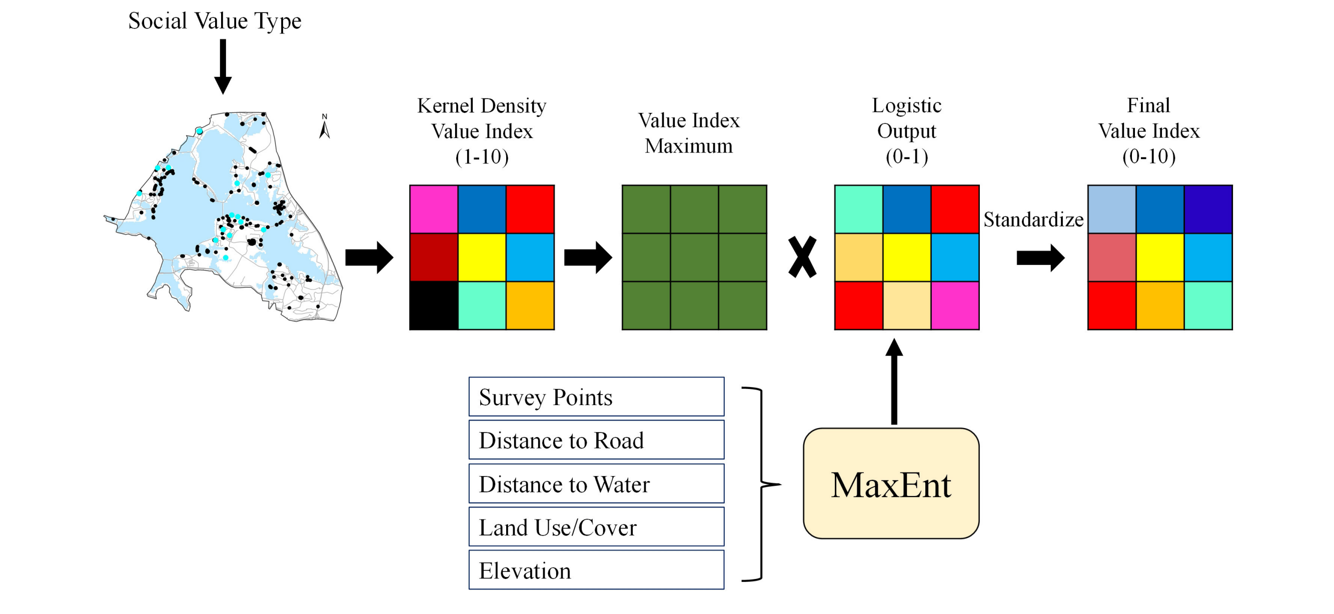

FIGURE 1 | Work flow of data processing in SolVES, adapted from Sherrouse et al. (58).

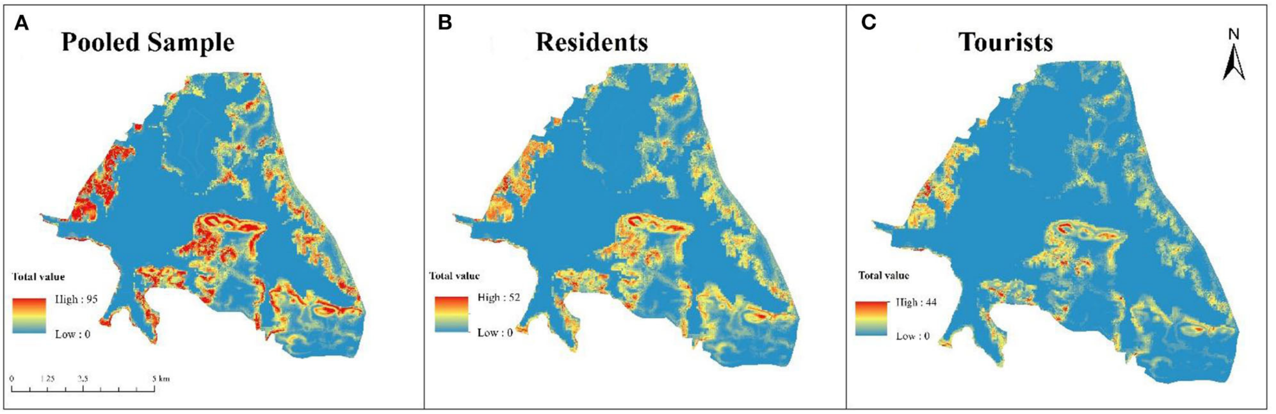

FIGURE 2 | Spatial distribution of total social value at ELSA.

generated by MaxEnt predict socially valued locations on the basis of point data that we collected using PPGIS and big-data approaches. The relationship between assigned social values and four primary environmental layers were determined using zonal statistics generated from the integer Value Index (from 0 to 10). The zonal statistics (mean value for continuous data; majority values for categorical data) were compared using independent-sample *t*-tests that were then subjected to Bonferroni tests to neutralize the effects of multiple comparisons.

The accuracy and credibility of the results from the MaxEnt models was evaluated by dividing survey points into "training" and "test" data. MaxEnt parameters were set to reserve 25% of the survey points of social values as test data. The calculation of Area Under the Curve (AUC) in MaxEnt reflected the total area under the Receiver-Operating Characteristic plot (ROC) for the training and test data. Training AUC suggests the goodness-of-fit of the model to the study area, and the test AUC indicates the model's potential predictive capability. We judged our models' fit to the sample data and their predictive potential according to the criteria of Swets (1988): if AUC≧0.90 then the model is deemed good; if 0.90>AUC≧0.70 then the model is useful; and if AUC≦0.70, the model is deemed poor (59).

RESULTS

Spatial Patterns of Social Value

This paper examines the distribution of perceptual social value as its first objective. For the pooled sample, perceived social values are distributed spatially across the whole scenic area with high-frequency clusters at Moshan, Tingtao, and Chuidi

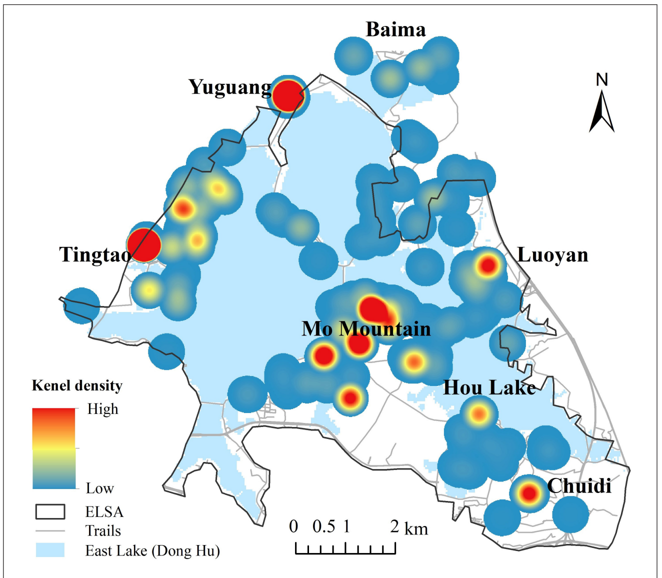

FIGURE 3 | Kernel density of digitalized scenic points at ELSA.

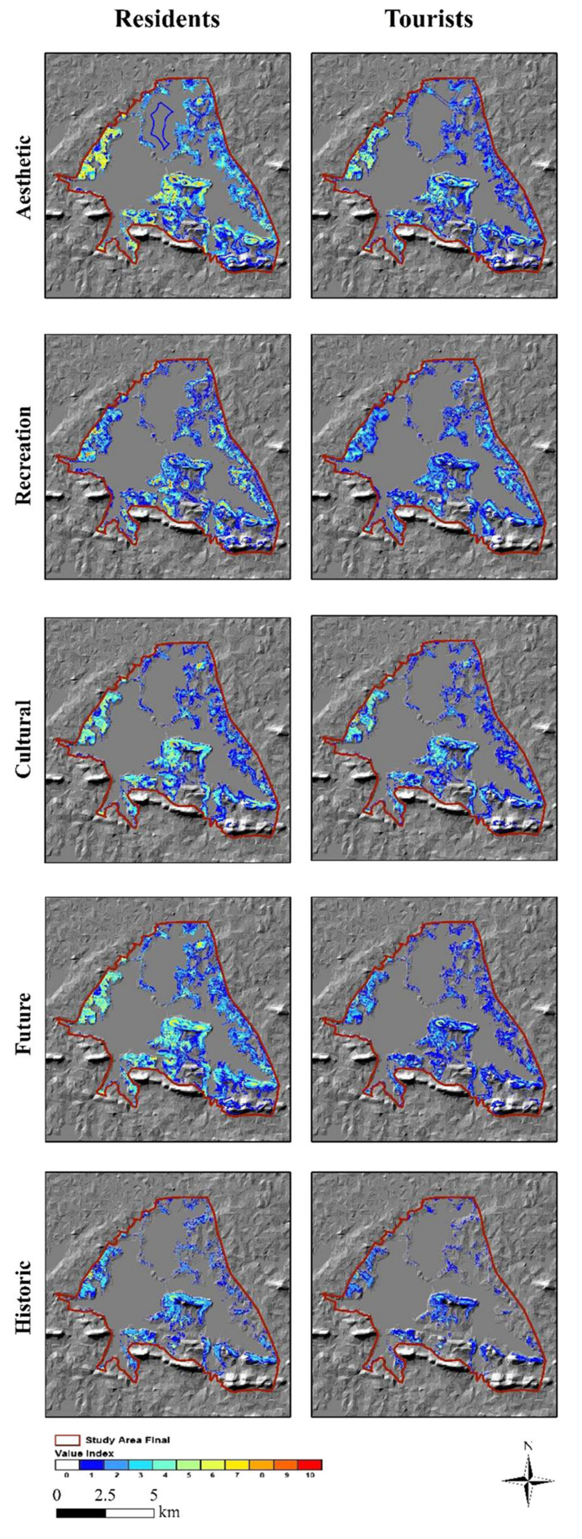

FIGURE 4 | Spatial patterns of five preferable social value indicators.

districts (**Figure 2A**). These clusters relate to digitized points at the Hubei Province museum, the botanical garden of the Chinese Academy of Science, Ma'an Mountain Forest Park, the East Lake wetland, and the museum remembering the poet Qu Yuan (**Figure 3**). Human activities like camping, hiking and cherry blossom appreciation within these locations increase the interaction with nature and thus contribute potential for higher value. Discrepancy between residents and tourists mainly existed in the location and coverage of their hotspots. Inhabitants tended to appreciate scenic points with various social value indicators across a larger geographic gradient spreading over the ELSA (**Figure 2B**). Inhabitants' assignments of high Value Index clustered in the Moshan and Tingtao districts. In contrast, tourists' distribution of social values encompassed a smaller portion of the ELSA (**Figure 2C**).

Disparity of Perceptual Social Value Indicators Between Inhabitants and Tourists

In response to the second objective, we identified the five most important perceived social values: recreation, culture, history, future, and aesthetic values (**Figure 4**); the Value Index of each was greater than six (58). To be specific, recreation hotspots at Tingtao, Mo Mountain, Chuidi, Luoyan districts, were the most popular parts of the ELSA. The Value Index assigned by residents (VI = 10) was higher than that assigned by tourists (VI = 6), indicating that recreation value was perceived more important by residents. Hubei Province Museum and the Chutian sightseeing platform embodied cultural value for both inhabitants and tourists. Notably, the cultural value score assigned by residents was higher than that assigned by tourists in the Baima district, probably because its greater distance from the commercial center and inconvenient transport impede visiting from tourists. On the contrary, locations like the National Park Museum, university, and Ancient Stories attract local residents who have better access to these scenic points. Future and history value had the same Value Index (residents: VI = 7, VI = 7;

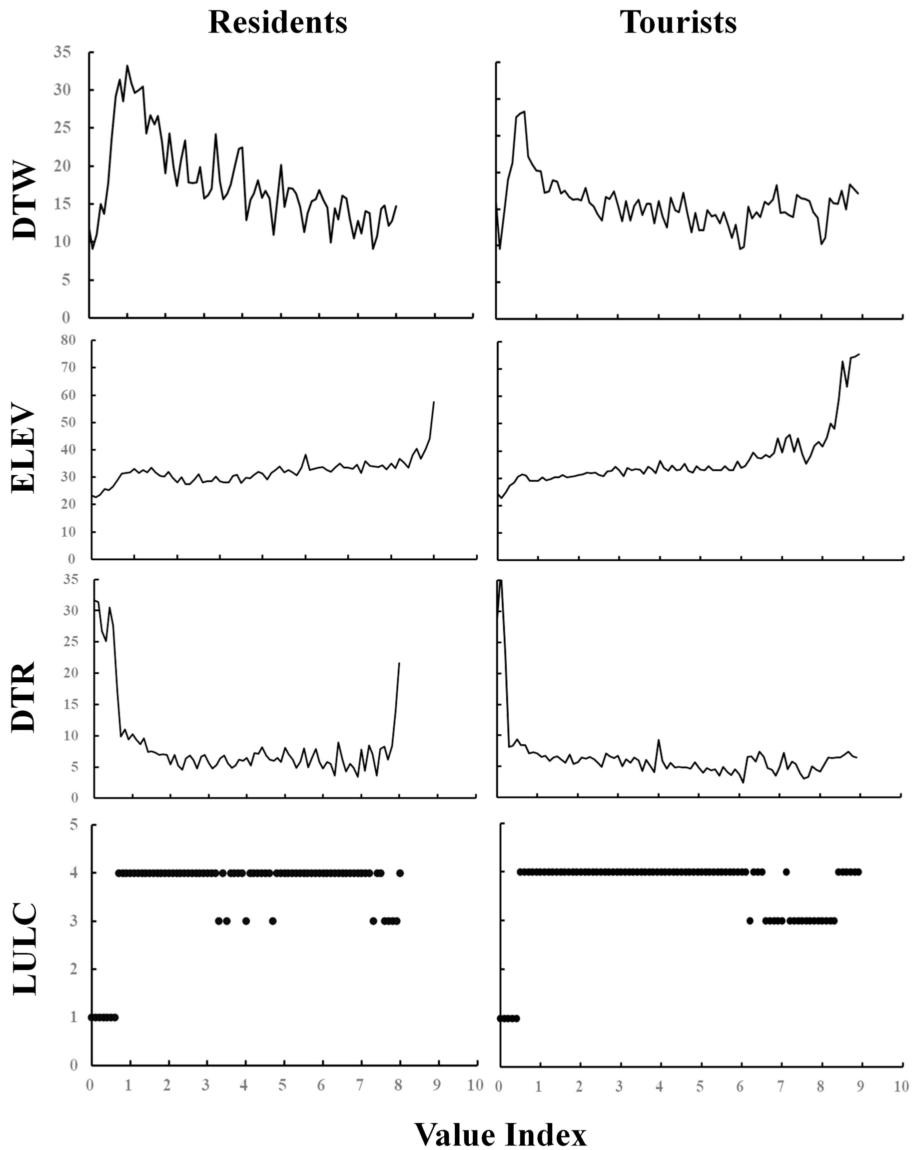

FIGURE 5 | Relationships of aesthetic value and environmental layers. DTR, distance to road; DTW, distance to water; ELEV, elevation; LULC, land use/cover. 1 represents lake, 3 is construction and 4 is forest.

tourists: VI = 7, VI = 7), suggesting that historic evolution and future promotion of the ELSA were considered equally important by residents and tourists. Aesthetic value perceived by tourists (VI = 9) was higher than that perceived by residents (VI = 8), although the spatial distribution was smaller and clustered around Mo Mountain and the Tingtao district, near to subway and bus stations. Residents' ready access over the whole of the ELSA leads to a far-ranging distribution of aesthetic value.

Relationships Among Preferable Social Values and Environmental Conditions

In response to the third objective, relationships among the five important social value indicators and four environmental layers were analyzed. For example, **Figure 5** demonstrates the relationship of aesthetic value with primary surroundings. Specifically, the intensity of preferences for aesthetic, cultural, recreation, future, historic values increased as: (1) the distance to road decreased; (2) the elevation increased. As the distance to water increased, aesthetic, future, recreation Value Indexes decreased with delicate differences in the downward trend between inhabitants and tourists. For cultural value, greater distance to water reduced the value recognized by tourists, while cultural value perceived by residents fluctuated. The analysis of relationships with categorical land cover demonstrated similarity between the two stakeholder groups. In detail, the five social value indicators showed lower scores around lake, and higher scores around construction and forest. Furthermore, the contributions of environmental layers to each value differed according to percent contribution (PC). For residents, aesthetic and recreation value were more influenced by distance to water, while cultural,

TABLE 4 | AUC results for resident and tourist groups.

Value type	Residents			Tourists		
	Training AUC	Test AUC	SD	Training AUC	Test AUC	SD
Aesthetic	0.921	0.909	0.014	0.924	0.918	0.007
Biodiversity	0.867	0.850	0.027	0.881	0.861	0.022
Cultural	0.930	0.935	0.010	0.934	0.951	0.004
Economic	0.940	0.929	0.013	0.933	0.941	0.009
Future	0.912	0.894	0.019	0.928	0.934	0.007
Historic	0.944	0.941	0.014	0.952	0.951	0.005
Intrinsic	0.924	0.934	0.019	0.919	0.940	0.012
Learning	0.906	0.914	0.020	0.939	0.940	0.008
Life sustaining	0.887	0.849	0.020	0.887	0.858	0.019
Recreation	0.918	0.920	0.012	0.914	0.903	0.011
Spiritual	0.899	0.921	0.012	0.899	0.868	0.015
Therapeutic	0.852	0.799	0.025	0.838	0.871	0.020

SD is the abbreviation of Standard deviation; AUC means area under curve.

future, historic values were significantly affected by land cover (**Appendix Table 1**). As to tourists, only recreation value was impacted by distance to water, while the remaining values significantly correlated with land cover. In general, distance to water and land cover exerted more effects on social values. The credibility and accuracy of models were assessed through the training AUC, indicating useful predictive ability (**Table 4**).

DISCUSSION

We focused on the disparity of perceived social values associated with ecosystem services for UGS of the ELSA by combining an on-site survey with social media data to provide a better understanding. Comprehensive consideration of social values for ecosystem services at ELSA will be informative to local management and spatial planning. Differing from the monetary evaluation of ecosystem services and geographical investigation, social values of ecosystem services are more suitable for integrating people and natural surroundings into decision-making (60). We classified visitors into urban residents and outside tourists to analyze the perception disparity. These subgroups differed in two aspects: firstly, the spatial distribution and location of social value hotspots; secondly, perceptual importance of social value indicators.

Our results suggest that the spatial pattern of perceptual social values differs between residents and tourists. Residents tended to perceive higher value scores and larger spatial scale of social values than tourists, as a result of constrained transport and familiarity with the scenic spots (26). Our results indicate an urgent need for decision-makers to target spatial planning, for instance, strengthening the accessibility and connectivity among sightseeing spots to facilitate tourist circulation, and extending fundamental service infrastructure for inhabitants. Differences were also found in the social value indicators. Recreation and economic values were more important to inhabitants than tourists, conversely the perception of cultural and aesthetic values. Given that the ELSA makes a difference in offering job opportunities and local economic development, it is not surprising that residents would like to pay more attention to recreation and economic value. Cultural and aesthetic values were rated higher by tourists, suggesting that beautiful scenery of natural and humanistic environment were considerable attractions to visitors.

As for value indicators, aesthetic value appreciated by stakeholders was in agreement with previous studies, because the visuality of scenic spots directly related to the reported perceptions (61, 62). The amusement park and aquarium enhanced the recreational value of the ELSA. Cultural, future and historic values were often collocated in places like the Hubei Province Museum. Future and historic value were equally valued by tourists and residents, which was in accordance with the Chinese construction of ecological civilization and Sustainable Development Goals (SDGs) appealing to sustainability. Residents and tourists share common characteristics in perceptual social values of UGS, suggesting that measures to improve the biodiversity, entertainment facilities, and cultural identity of the ELSA would enhance the relevant perceived social values.

Relatively less important social value indicators, including learning, biodiversity, life-sustaining, intrinsic, spiritual and therapeutic values obtained lower scores. The reason might relate to these values being less tangible and effable. However, life-sustaining and biodiversity values represent the ecological quality of the natural environment, and people benefit from spiritual and therapeutic experiences. Thus, we have emphasized prioritizing preferable values and also taking those neglectable, but fundamental, values into consideration.

Regardless of survey subgroup, the Value Index of social values like aesthetic, future and recreation were higher and closer to roads and water, and at higher elevations. Among the four environmental layers, distance to water (DTW) contributes around 50% to the social value score (**Appendix Table 1**). This can be attributed to the lake surface occupying 37.5% of the total area. Land use/cover is another important layer for aesthetic, cultural, future and historic values, indicating that landscape composition influences the perceived social values. Elevation contributes about 20% to social values for residents and tourists alike. Since the trail network provides adequate access to every corner of the ELSA, distance to road (DTR) did not exert a significant contribution to social value indicators except for economic values. Spatial planning for increasing opportunities to approach water and vegetation coverage will hence strongly foster social values.

Disparities between residents and tourists mainly exist in the proportion contribution of environmental layers. Taking aesthetic value as an example, distance to water takes up to 60.2% and is the primary influential layer from the perspective of residents. For tourists, distance to water and land use/cover contribute to 34.7 and 37.7%, respectively. Large water surface is propitious to local climate and temperature regulation. Besides, camping and boat sailing are representative activities of residents relating to water. Tourists equally appreciate both water and landscapes in aesthetic value. Perceived aesthetic value will therefore be promoted by the addition and improvement of facilities near water. And better allocation of land cover exerts positive effects on tourists larger than that on residents.

On-site survey and social media data have become the main source of data collection in the evaluation of social value for ecosystem services (63, 64). The advantages of on-site surveys can be found in detailed publications about respondents and empirical methods (65), although survey administration is limited by time and economic cost, and also by spatial and temporal restrictions (e.g., investigation of remote natural areas and historical situations) (66). Social media compensates for these disadvantages and is recognized as a free, fast and useful source of data (67). We attempted to combine the advantages of both kinds of data in this research. The results suggested that the on-site survey compounded well with social media, for analysis using the SolVES tool. A longer-timespan data source could provide abundant temporal information, potentially applicable to dynamic analysis of ecosystem services over a time cycle. Different data sources offer ways to develop a more comprehensive knowledge of social values of ecosystem service for UGS.

CONCLUSIONS

This research combined environmental characteristics with subjective perceptions of visitors to quantify, assess and map social values across the East Lake Scenic Area. We combined on-site survey responses with social media data into a comprehensive knowledge-base of location-associated social values, allowing an analysis of how social values relate to environmental characteristics, and how those associations differ between inhabitants and tourists. Results demonstrated that the spatial pattern and Value Index of social values could be associated with surrounding layers. Residents and tourists differed in distribution of social value, the importance of value indicators, and which environment layers were most influential to their experiences. Integrating different data sources extends the data acquisition approaches available for the SolVES model, which could potentially visualize the temporal dynamics of social values in the long run. Moreover, this study emphasized the social value discrepancies between residents and tourists to provide insight into how demands of different stakeholder groups can be incorporated into urban planning and green space management processes. Similar studies in other regions of the world are necessary to examine how different data sources and different stakeholders' categories could contribute to urban green space planning.

Two limitations need to be addressed in this study. Firstly, we conducted the on-site survey only once during 1st−4th May, spring of 2019. People's perceptions in every season or month should be surveyed for the purpose of coordinating with the whole year's social media data. Additionally, on-site surveys and social media data collection are subject to sampling bias. Because young adults are the main users of Sina Blog, opinions of young children and aged people are less considered (68). Future research should consider a fuller range of age categories to provide more comprehensive understanding.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

Ethical approval for this study was not required in accordance with local legislation and national guidelines.

AUTHOR CONTRIBUTIONS

YC: designing, writing the manuscript, and data processing. XK: revising the manuscript. MM: designing the structure and revising the manuscript. PC: data processing. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

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Understanding the Well-Being of Older Chinese Immigrants in Relation to Green Spaces: A Gold Coast Study (Australia)

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In recognition of the aging population and the importance of health-supporting urban environments, including urban green spaces, to maintain well-being, scholars and policymakers have increasingly investigated the associations between urban green spaces and the well-being of older people. However, few studies specifically investigate minority older groups such as those with diverse cultural backgrounds, and many studies often ignore the design attributes of green spaces which may contribute to the well-being of those in such groups. In order to address these gaps, this paper explores how green spaces influence the well-being of older Chinese immigrants. This case study analyzes how older Chinese immigrants interact with green spaces on the Gold Coast, Australia, and adopts the value of place as a conceptual framework to understand the relationship. Two qualitative methods, namely, in-depth interviews and travel diaries, were used to collect data. The results show that parks, as a place, play a crucial role in older Chinese immigrants' ability to undertake outdoor activities. The relationship between green spaces and well-being can be classified into two themes. The first theme is concerned with how older Chinese immigrants perceive and experience green spaces. This finding indicates that green spaces can fulfill their values of keeping healthy, maintaining active lifestyles, and being social, all of which benefit well-being. The second theme relates to daily activities undertaken within green spaces. Issues of accessibility and personal preferences regarding activities complicate the relationship between green spaces and well-being. Good accessibility to green spaces is congruent with older Chinese immigrants' values of being physically active, while difficulties in conducting preferred activities counteract these values which then generate negative perceptions of green spaces. Overall, there is great potential for understanding how personal values can inform the design of inclusive green spaces for minority or less mobile groups.

Keywords: green space, values, accessibility, older Chinese immigrants, well-being

INTRODUCTION

The number of urban inhabitants worldwide is expected to reach 6.6 billion by 2050, an increase of 52% from 2020, and of this 16% will be above 65 years old (United Nations, 2019). Human health and well-being are becoming priority goals for urban planners and city governors (United Nations, 2016), and urban green spaces are being regarded as an important urban environmental element that provides social, medical, and economic benefits (Bell et al., 2014; Douglas et al., 2017). For example, Lee and Maheswaran (2010) have indicated that urban green spaces promote well-being through reducing exposure to air pollution, noise, and heat. Neuvonen et al. (2007) and van den Berg et al. (2010) have shown how green spaces provide functions of psychological restoration and others, such as Hunter and Luck (2015), Sandifer et al. (2015), and Liu et al. (2019a), have demonstrated how green spaces facilitate physical activities and social engagement for residents. However, existing studies are often based on a premise that is centered around a general population. In other words, previous studies understand residents as a single and homogeneous group when investigating the relationships between green spaces and well-being (Hitchings, 2013). Obvious disadvantages of this approach include the lack of representativeness, as diverse minority populations (e.g., ethnic, age, or gender-based) are backgrounded and the influence cultural factors can have on the relationship between green spaces and well-being is ignored (Rishbeth et al., 2018). These gaps in research highlight the need for a further detailed investigation of the different benefits green spaces can offer to minority group members, as this may help urban planners and policymakers efficiently construct urban green spaces in the future (Douglas et al., 2017).

In this study, public green spaces describe natural areas in urban settings such as parks, gardens, woodlands, rivers, and beaches, which may incorporate natural, semi-natural, and artificial areas (Tzoulas et al., 2007; Bell et al., 2014). Public green spaces are an essential component of the urban green framework that can be accessed freely by the city population. These public green spaces are particularly important for minority and vulnerable residents who rely heavily on public spaces for leisure and recreation (Berney, 2010). However, in many cases, the public green spaces are distributed unevenly in urban areas, leading to urban residents not having equal opportunities to use public green spaces (You, 2016). Public green spaces have broader social significance in urban places (Barbosa et al., 2007) and, as a result, is a main concern within this research.

This research specifically investigates older people (in this research, older people are regarded as people who are aged 55 years old and above, based on Chinese statutory retirement age), as they are the fastest-growing age group worldwide (Wiles et al., 2012). Some institutions have published planning recommendations to help maintain the well-being of older people, including the milestone framework *Global Age-Friendly Cities: A Guide* published in 2007 by the WHO, which identified green spaces as a vital component of age-friendly cities (WHO, 2007). Interacting with green spaces on a daily basis can promote physical activity, decrease sedentary behavior, and reduce stress experienced by older people, positively impacting on their well-being (Wen et al., 2018). Another focus of this study is ethnicity, as the emergence of international immigration has resulted in an important demographic change globally that has seen the older population become more diverse racially and ethnically as a group (United Nations, 2019). As of 2016, in Australia specifically, over one third (37%) of older people were born overseas (Australian Bureau of Statistics, 2018a), with this number projected to increase rapidly until 2050 (FECCA, 2015). Among this minority-diverse group of older people, the older Chinese is one of the fastest growing groups, ranking as the third largest minority population nationally (Australian Bureau of Statistics, 2016a). Older Chinese immigrants who move to Australia later in life often aim to reunite with and support their adult children. They usually are not sure how long they will live in Australia. Immigration is the transnational movement with the intent of becoming a permanent resident of the destination country, while migration is the temporary movement. Their status of movement is in between and suspended, and thus they can be known as "parenting immigrants."

Aging and living in a foreign country can lead to multiple vulnerabilities, including a decrease in mobility, weak mental health, high risk of social exclusion, and an increased need for recreational activities in green space (Byrne and Wolch, 2009). Language barriers and the inability to drive and/or take public transport can result in unfamiliar and stressful environments, which tend to increase the physical vulnerability of older Chinese immigrants (Tieu and Konnert, 2014; Lin et al., 2016; Luo and Menec, 2018). Considering the vulnerability of older immigrants, healthy aging of older immigrants is increasingly important. Healthy aging is defined as "the process of developing and maintaining the functional ability that enables well-being in older age" (WHO, 2015, p. 28). Green spaces that maintain older immigrants' active lifestyles and independence could positively contribute to their healthy aging and overall well-being (de Keijzer et al., 2020). The multidimensional relationship that community members have with green spaces contributes to the unified understanding of well-being that integrates physical, social, and mental well-being into one concept (Ziegler and Schwanen, 2011). In this research, well-being is defined as a subjective phenomenon that describes people's experiences of how well they are or how well they live (Fleuret and Atkinson, 2007; Ziegler and Schwanen, 2011).

Some scholarly work already exists on how minority groups use green spaces (Golledge, 1997; Byrne and Wolch, 2009). These studies demonstrate that people with different cultural backgrounds exhibit varying preferences for and engagement with different green spaces (Özgüner, 2011; Jay et al., 2012). For example, Byrne and Wolch (2009) showed that the White Americans may seek opportunities to exercise in green spaces, while Latinos sought to socialize. Green spaces express different meanings of place to people with diverse cultural and ethno-racial backgrounds (Egerer et al., 2019). Thus, it could be inferred that the benefit of green spaces may vary depending on the culture and the values of visitors. However, globally to date, little empirical research, including in Australia, has explored how cultural values influence the perceptions that minority group members have of green spaces and how their sense of well-being is gained. This study is focused on understanding green spaces and how they influence the well-being of older Chinese immigrants, within an Australian multicultural context through a lens situated in Chinese values and beliefs. The aim is to provide insights into why and how designing green spaces can better maintain the well-being of elderly immigrants in Australia.

Finally, the values of older Chinese immigrants are used to link the relationship between well-being and urban green spaces. Values are abstract concepts that are indicated by goals and accomplishments in daily activities (Tiberius, 2014). With this in mind, the specific values and the activities related to green spaces which are considered vital by older Chinese immigrants may have a role to play in their perceptions of green spaces and their well-being. These research stems from the hypothesis that people's well-being and positive perceptions and attitude depend on what extent their values had been fulfilled (Sagiv and Schwartz, 2000; Schwartz, 2012). For older Chinese immigrants, the disjunction between current urban green places and their entrenched daily practices can impede their ability to fulfill their values, which can lead to negative perceptions of green spaces and thus also their well-being (Hodgetts et al., 2010). Therefore, investigating activities undertaken by older Chinese immigrants in green spaces assists in the understanding of the values, then perceptions, and well-being of members of this group.

The participants in the study are Chinese immigrants residing on the Gold Coast, Australia. Although Chinese immigrants usually settle in two major cities – Sydney and Melbourne, an increasing number have chosen to live in other cities since 2000 (Wang et al., 2018). On the Gold Coast, between 2006 and 2016, the number of Chinese immigrants rapidly increased from 2,945 to 8,408 (Gold Coast City Council, 2016). Chinese immigrants who were over 55 years old more than tripled and reached 1,694 in 2016, accounting for 20.1% of total Chinese immigrants on the Gold Coast (Australian Bureau of Statistics, 2016b). More specifically, Chinese immigrants have become Gold Coast's top non-English speaking population in 2016, ranking up from a fifth position in 2006 (Wang et al., 2018). With the Gold Coast having an increasingly multicultural profile and rapid urbanization, it seems important to understand the immigrants' interactions with the urban environment in order to meet diverse environmental needs.

As such, this research aims to examine important values held by older Chinese immigrants while exploring pathways that link public green spaces to their values and, therefore, well-being. The research questions are (1) to what extent do public green spaces influence the daily activities and well-being of older Chinese immigrants? and (2) how do older Chinese immigrants' values influence their perceptions of public green spaces on the Gold Coast, Australia? Understanding these values may contribute to the development of future policies that work to design more inclusive urban green spaces.

METHODOLOGY

Older Chinese immigrants living in the City of Gold Coast were involved in this study to explore how members of cultural and ethnic minority groups interact with urban green spaces. The Gold Coast is located on the eastern coast of Australia. Its 57-km coastline, spreading canals, and vast natural environments with a subtropical climate create a special urban form and park landscape (see **Figure 1**). The average temperature ranges from 16 to 29°C, with approximately 300 days of sunshine per year, and the mean annual rainfall depth is around 1,300 mm (Bureau of Meteorology, 2020). The parks on the Gold Coast accumulate to 19 million sq. m of land with various facilities for cycling, barbecuing, walking pets, and fishing (Gold Coast City Council, 2020). Residents on the Gold Coast have an abundance of green spaces, with 47.8 sq. m per capita. Among these public green spaces, the proportion of local parks, metropolitan parks, and regional parks are 57, 14, and 29%, respectively (Byrne et al., 2010). However, less than half of parks on the Gold Coast are accessible by public transport (Byrne et al., 2010). The mild climate, good air quality, copious amount of sunshine, and lifestyle continuously attracts an increasing number of immigrants to move to the Gold Coast, resulting in this city being one of the fastest-growing regions in Australia (Dedekorkut-Howes and Bosman, 2015; Bosman, 2016).

It is hypothesized that increased cultural and ethnic diversity will require a new strategy for urban green spaces. Therefore, this research examines the perspectives of older Chinese immigrants to determine features of urban green spaces that are relevant to their well-being. We draw from a mixed method combining travel diaries, mapping, and interviews to provide an in-depth exploration of green space visitation among older Chinese immigrants on the Gold Coast. First, travel diaries, as developed by Winters et al. (2015), were completed by participants to understand their activities, time-use patterns, and spatial travel behaviors within a single week. Then, with the help of an interviewer, the participants drew the travel routes to green spaces. Interviews were finally conducted, guided

FIGURE 1 | Aerial photo of Surfers Paradise on the Gold Coast facing west (photo by Siyao Gao).

by the data of travel diaries and spatial patterns of activities. The interviews informed the quantitative data in greater depth. The quantitative data were used to understand the visitation patterns of older Chinese immigrants and also analyze and explore the participants' experiences.

The participants completed travel diaries with the assistance of the interviewer. The interviewer sent reminder messages to the participants every 2 days to decrease the likelihood that the participants might miss any activities. The participants recorded details of each trip to green spaces, including the origins and destinations of the trip as well as other related temporal information, such as how they get to the destinations, their travel companion, and why they visit green spaces (e.g., exercise, recreational, or social purposes, etc.). The data from travel diaries were cleaned and entered into a SPSS database and used to describe the activity patterns of older Chinese immigrants. The participants were also asked to locate the green spaces they went to and the related travel tracks to these green spaces within their travel diaries. A total of 18 participants completed the maps (two couples participated, so the travel maps only show 16 houses). These mapping data were descriptively analyzed using ArcGIS software 10.3.

After the travel diaries and mapping exercises were completed, the first author conducted the interviews. Informed by the research objectives of this study, the research focused on the relationship between green spaces and well-being. Hitchings (2013) showed how qualitative approaches unveil subtle appreciations of the lifestyle and generate effective means of improving green space experiences; hence, this study adopted qualitative methods in the data collection and analytical process. The interviewees were prompted to provide details of their activities, movements, and experiences of visiting green spaces. Interview questions like "What did you do in green spaces before and after you immigrated to Australia?," "What are the contributors and facilitators of conducting activities in green spaces?," and "How do you perceive green spaces on the Gold Coast and in your hometown?" were raised. The well-being of older Chinese immigrants was self-rated in the process of the interviews. During the analysis of qualitative data, the proportion of participants with similar answers was calculated to show the overall situation.

Thirty participants completed the research at various places that they preferred, such as public parks, churches, and Chinese community centers. The interviews varied from 30 to 90 min. Mandarin, as the first language for both the interviewer and the interviewees, was the language used to conduct the interviews to minimize miscommunication in the research. During the analysis, the transcripts were translated into English by the interviewer and a proof-reader to ensure the accuracy of the translation and to avoid missing any cultural meanings as described by Suh et al. (2009). The participants were given pseudonyms to protect their identities while still denoting them as active and engaged subjects (Allen and Wiles, 2016).

This study used a purposive sampling strategy to collect the data (Liamputtong and Ezzy, 2005). In 2018, a preliminary study with six participants was conducted. By regularly attending Tai Chi classes and other social activities organized by Chinese organizations, the first author was able to establish a network of potential participants, with the assistance of local Chinese organizations. From February to May 2019, large-scale fieldwork was carried out. After gaining trust from potential participants, the first author recruited the participants by asking the participants' willingness to join the research. Before commencing the interviews, all participants were given information statements and required to complete oral or written consent forms. In terms of the criteria used to recruit the participants, the Chinese retirement policy states that the statutory retirement age is 55 years old for female staff or 50 for female blue-collar workers and 60 years for males (Feng et al., 2020). Therefore, in this study, older Chinese immigrants who were 55 years old and above were deemed eligible to participate in the study. To ensure that the participants were able to provide reliable information about both their hometown and the Gold Coast, a minimum length of 6 months of stay on the Gold Coast was also a requirement of participant eligibility.

The analysis of the qualitative data was based on comparative methods (Corbin and Strauss, 2014) to develop the themes. The transcripts were read verbatim by the first author to mark each segment of meaningful data with a series of codes (Miles and Huberman, 1994). These codes were carefully scrutinized and constantly compared to identify and construct themes according to their similarities and discrepancies. Codes with similarities were grouped into a theme, which organized the raw data into conceptual groups. The initial coding list was created prior to collecting qualitative data based on the research question and literature, including key language such as "green spaces," "physical activities," "social activities," "relationship between green spaces, activities" and "well-being," and "relationship between green spaces and well-being." In the process of coding, according to the concept of values that were embodied in the goals of visiting green spaces, "keeping healthy," "active lifestyle," and "community inclusion" were included as emergent codes. Finally, these codes formed core themes that offered some insight into the relationship between green spaces and well-being. The transcripts were analyzed with the aid of the qualitative software NVivo 12.

RESULTS

Overall, the sample included 11 males and 19 females. Their ages ranged from 61 to 83 years old (the average age was 69.4 years old), with 70% aging between 65 and 80; at the time of the interviews, their length of stay in Australia ranged from 1 to 15 years (the average length was 5.5 years). Among these participants, 17 participants lived with both their spouse and children's families, 10 participants lived with their spouses only, and three lived with their adult children only, without a spouse. These participants lived in various types of neighborhood with different levels of accessibility to green spaces. The neighborhood types where the participants resided were characterized as low, medium, and high advantage using the Socio-Economic Indexes for Areas. This index was determined by income, education, employment, occupation, and housing characteristics of the neighborhood (Australian Bureau of Statistics, 2018b). In this research, out of the 18 participants who provided their residential addresses, seven of them lived in high-advantage neighborhood environments, and the remaining 11 participants lived in medium-advantage neighborhood environments. Regarding the participants' neighborhood environment, according to the standards proposed by the Gold Coast City Council (2019), six participants lived in high-density zones with high accessibility to public transport, community facilities, and green spaces, while the remaining 12 participants lived in suburban areas far away from public infrastructures.

Three themes were established from the research. The first theme centered around older Chinese immigrants' daily patterns of visiting green spaces. The second focused on contradictions between preferences of activities and barriers associated with green space visitation. Finally, values embodied in visiting green spaces, including values of keeping healthy, maintaining an active lifestyle, and being social, are analyzed.

Patterns of Everyday Contact With Public Green Spaces

Descriptive statistics were used to depict the general pattern of green space visits undertaken by the participants. The travel diary was completed by 30 participants who documented 380 trips within 7 days. The result indicates that public green spaces are the main destinations for older Chinese immigrants. Among these trips, nearly one-third of trip destinations (101) were to parks near their homes, and all of these trips were made on foot. A total of 45 trips were to other parks, which accounted for 11.8% of all trips. The participants went to other parks by various means of transportation, including private cars, walking, and public transport.

The patterns highlighted, based on the time of visits to the green spaces within a day, indicated two clear waves of visiting hours (**Figure 2**). Mornings (6:00–9:00) were the most preferred time, according to these participants, to visit both parks near home and other parks, while late afternoons (16:30–18:00) were popular for visiting parks near homes only. Visiting green spaces in the morning may be attributed to activities such as Tai Chi or social activities often being considered and therefore organized as morning activities. Additionally, 66.7% of participants expressed their willingness to visit the spaces in the evening.

As for the type of companions that made these visits with the participants, the participants mostly favored visiting public green spaces with their spouses (47.6%), alone (21.9%), or with friends (19.8%). Visiting with pets or family was less favorable, with these companions only preferred by 7.5 and 3.2%, respectively. The result indicates that green spaces offered a place for them to conduct activities independently. As Bei (female, 64 years old, living in Australia for 3 years) pointed out:

> "I can't drive or take buses here. The small park near my house is a place for me to visit independently. I can go to that small park at any time without asking my son to drive me there. I can enjoy time by myself."

The individual activity patterns of the 30 studied participants in urban green spaces are shown in **Figure 3**. Walking was by far the most popular activity undertaken in public green spaces (66.5%), while social activities were the second most frequent (14.2%). Social activities included having conversations, exercising, and having recreational activities together. The proportions of those who walked pets and played Tai Chi were 6.4 and 6.0%, respectively.

The Influence of Preferred Activities and Accessibility

The high accessibility of green spaces encouraged the participants to visit these spaces and conduct more physical activities. Yi (male, 71 years old, living in Australia for 1 year) noted:

> "The park is near my home, only 2 minutes' walk. It's really convenient. If I have time, I will go to that park and sit for a while."

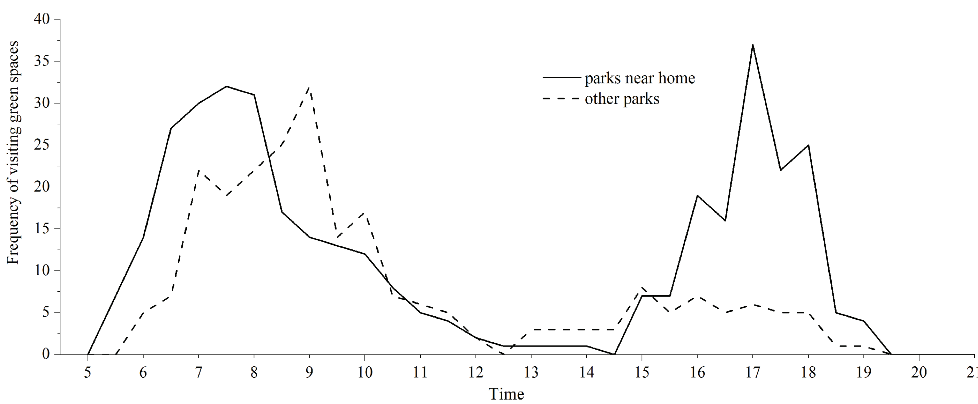

FIGURE 2 | Timing of visits to urban green spaces.

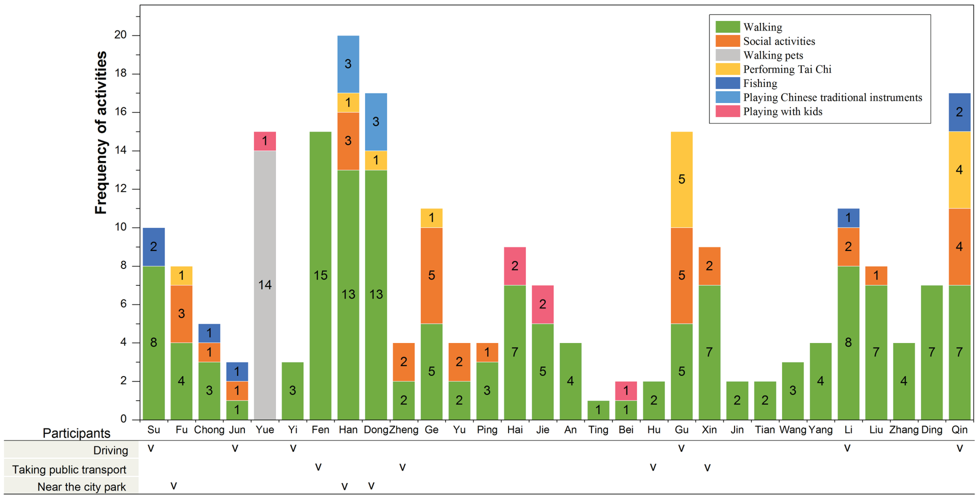

FIGURE 3 | Individual activity patterns of participants ("v" indicates that the participants have the ability to drive or take public transport on the Gold Coast or live near the city park – these groups of people are regarded as having high mobility; participants without a "v" have limited mobility).

The participants who were able to drive or take public transportation on the Gold Coast or lived near city parks that hold Chinese activities are classified as having high mobility. Others are seen as having low mobility. Differences between low and high mobility were examined using *t*-tests. The comparative analysis between the high- and low-mobility groups resulted in significant differences (**Figure 4**). Compared to participants who were considered "less mobile," those who were "more mobile" ($n = 13$) had a higher frequency of visiting green spaces ($p = 0.019$) and conducted more types of activities in green spaces ($p = 0.003$). Yue was an exceptional case. Yue had low mobility but had to walk the dog twice a day, which significantly increased her frequency of visiting green spaces.

Issues of accessibility and personal preferences regarding activities complicated the relationship between green spaces and well-being. For instance, older Chinese immigrants preferred green spaces that supported their ability to partake in Chinese activities. On the Gold Coast, all (100%) participants reported that they still retained a willingness to continue their previous lifestyle and physical activities in green spaces, such as performing Tai Chi, square dancing, and singing. Gu (male, 63 years old, living in Australia for 2 years) stated his experience:

> "I like performing Tai Chi. I practiced Tai Chi for nearly 10 years before I moved to Australia. Now, I've joined a Tai Chi club, and I can continue to practice it."

As indicated in **Figure 3**, one-fifth of the participants performed Tai Chi within 7 days before the interview. Two participants, Dong and Han, a couple, played traditional Chinese instruments in the park near their homes. The participants revealed that the activities that they preferred, such as Tai Chi and square dancing, were mostly clustered in the city parks on the Gold Coast. The participants' residences were scattered across the Gold Coast, which meant that few of the participants were able to visit their preferred parks. **Figure 5** shows the travel maps of the 18 participants within a 1,000-m zone highlighted on each map. It showed that the participants' behavior in visiting parks and their travel tracks depend on the distribution of parks within a 1,000-m zone (see **Figures 5A–C,E,F**). They could walk to the parks near their home, which indicated that the accessibility of parks could partly meet the participants' needs. However, they had lower accessibility to their preferred park. As shown in **Figure 5D**, people who were able to drive or take public transportation could go beyond the 1,000-m zones, visit the city park, and participate in dancing, Tai Chi, and other preferred activities, while others were limited in their ability to do this, as they could only visit neighborhood green spaces within their 1,000-m zone. More than one-half (57%) of the study participants reported that they could barely conduct the physical activities they preferred. For example, as Yue (female, 61 years old, living in Australia for 2 years) complained:

> "Actually, there is a park that has activities such as square dancing and Tai Chi. Many older Chinese people do these activities there. But I can't go there by myself. So, I can't join them."

Older Chinese immigrants had accessibility to visit green spaces near their homes. The fact that they were unable to visit the parks that they preferred negatively influenced their perceptions on green spaces on the Gold Coast.

Values Embodied in Green Space Visitation

Three main types of values pertaining green spaces emerged through the analysis of the interviews, namely, keeping healthy, maintaining active lifestyles, and being social.

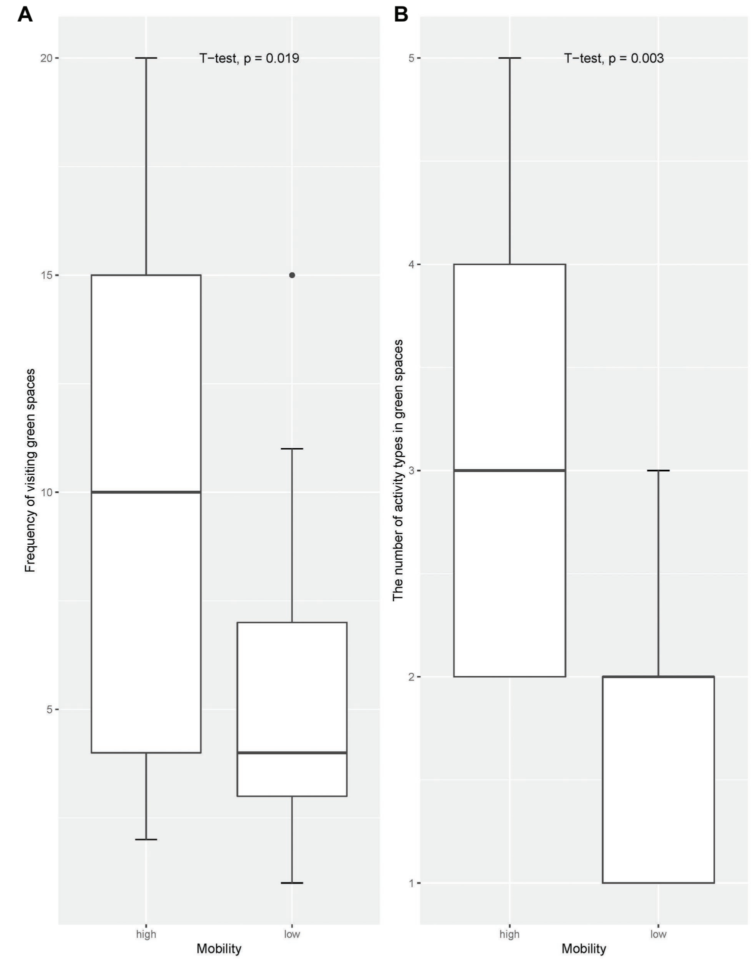

FIGURE 4 | Box plot illustrating the frequency of visits to green spaces and the types of activities undertaken with reference to the participants mobility level. **(A)** Comparing frequency of visiting green spaces between high and low mobile groups. **(B)** Comparing the number of activities undertaken in public green spaces by high- and low-mobility groups.

The Value of Keeping Healthy

The participants expressed at length that their most essential purpose of visiting public green spaces was to remain healthy, which embodied the participants' values of keeping healthy. The participants perceived that green spaces provided a healthy landscape and place to undertake exercise. First, all (100%) participants noted that exposure to green spaces provided pleasure and positive feelings. They pointed out the positive elements that formed a healing landscape for them, including what they saw, heard, and felt, such as the quiet and peaceful scenery, lawn, tree-shade, birdsongs, temperature, and winds. They showed sensitivity to the landscape and awareness of its health benefits. The participants developed a sense of improved health when they visited green spaces, congruent with their values of maintaining health, and thus this also generated positive perceptions of green spaces. As Hu (female, 70 years old, living in Australia for 9 years) pointed out:

> "I am happy to live here. The parks here make me feel close to nature. They provide an open space where I can sit and gaze into this landscape. I can feel the warm sunshine, see the beautiful scenery, and hear the birdsong, which helps me escape from annoyances. It is definitely good for my health!"

The participants also perceived green spaces as providing opportunities to conduct physical activities based on their values of keeping healthy. According to the data drawn from the travel diaries, nearly all (93%) the physical activities or exercises undertaken by this group were conducted in urban green spaces, while the remaining 7% of physical activities were conducted in community centers or churches. This result alludes to the essential role of green spaces, as these participants heavily rely on these spaces for their physical activities. Fu reported:

> "I only do some simple exercises in the park near my home, such as walking or doing some stretching. Green spaces enable me to walk more. It's easy for me to walk 1 to 2 kilometers in the parks. It's good for our health. If I stay at home, I think I won't be able to go out anymore. That means my health may collapse. So, I go to the park every day."

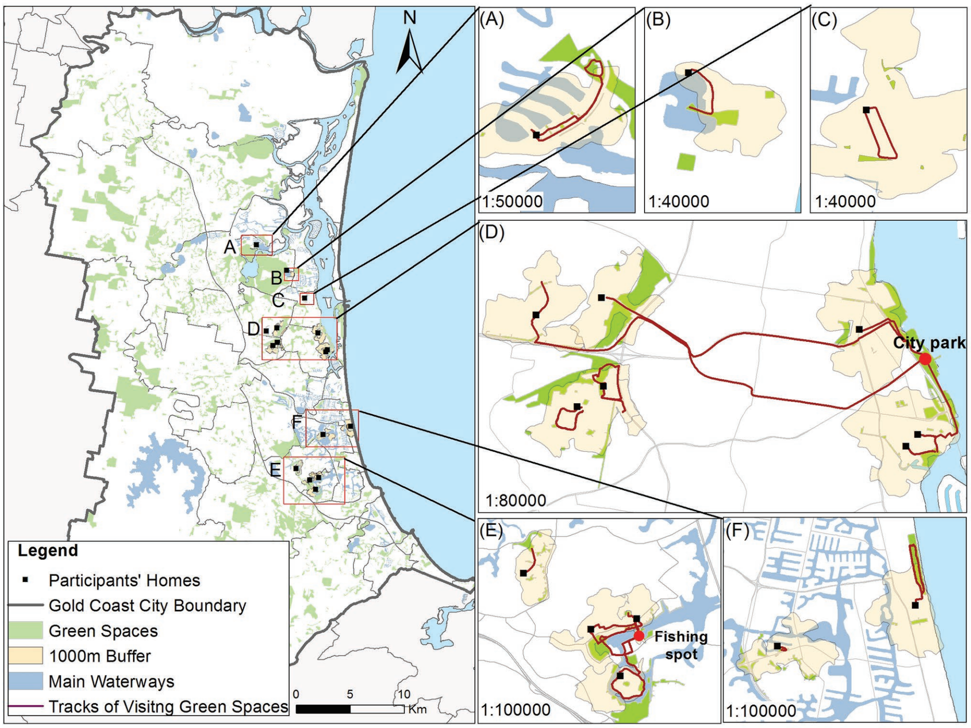

FIGURE 5 | The participants' location and their travel maps to green spaces on the Gold Coast. **(A-F)** show detailed participants' location and travel maps. (source: image produced by the author with spatial information obtained from the Australian Bureau of Statistics and the Gold Coast City Council).

However, older Chinese immigrants pointed out that green spaces on the Gold Coast cannot completely meet their needs of keeping healthy as they cannot always undertake particular Chinese activities that act as a means to fulfill their values of keeping healthy, such as performing Tai Chi, square dancing, and singing. It was discovered that few parks on the Gold Coast could meet such needs. The participants (57%) who could not undertake their preferred activities made modifications to compensate for these barriers in order to continue their ability to participate in physical activities. To some extent, walking was seen as a complement to their physical activity need. Because of the differences between the green spaces in China and in Australia, the participants fulfill their values of being active and healthy on the Gold Coast to a lesser degree, which has generated negative perceptions of green spaces as older Chinese immigrants are unable to continue the lifestyle that they had in China. Ping (female, 65 years old, living in Australia for 7 years) made the following comparison:

> "In my hometown, there are always various activities, such as square dancing and choir singing. I can participate in these activities. I always want to find similar activities here, but it's difficult. I only walk here, nothing else."

The Value of Active Aging

Another reason for which the participants visited a green space was to fulfill their values of maintaining an active lifestyle. Due to their reduced social network and limited mobility, 77% of the participants pointed out that they had fewer formal or informal activities after migration. However, all (100%) the participants visited green spaces at least once a week. The fact that all the participants visited green spaces reinforced their desired to have an active lifestyle in later life. They prioritized going to green spaces as a regular daily activity to spend leisure time and escape boredom. They perceived experiences with green spaces to be integral in experiencing a fulfilling day. As Fu noted:

> "I go to the small park to walk and do some exercise twice a day. Once is in the morning and the other is after my dinner. In China, I have lots of physical or social activities, but in Australia I have no place to go. So, going to the nearby park has become a thing for me; otherwise, I have nothing to do and I am always at home."

During the interviews, 70% of the participants compared the activities that they could undertake between their hometowns and the Gold Coast, indicating that they preferred the lively atmosphere in green spaces, mostly in China. Parks there were seen as public places which held various activities and created a vibrant place, as expressed by Ding (female, 65 years old, living in Australia for 5 years):

> "The parks in my hometown are lively; there are many people walking and chatting with each other. There are

also many activities, such as singing, dancing, and Tai Chi. It's a little bit crowded but lively. When I saw other older people doing these activities, I felt that I also had an active lifestyle."

More than half of the participants (60%) were unsatisfied with the green spaces on the Gold Coast during their green space visitation. They perceived that the monotonous landscape of green space could not fully meet their values of being involved in an active environment as Tian (female, 68 years old, living in Australia for 4 years) noted:

"Although the environment is good, it is boring. There is no other scenery I can see. The trees, flowers, and large lawn are always the same. You can see a few people walking or running. I feel bored."

The Value of Being Social

The third important function of green spaces as described by the participants is how they enable the construction of social connections with people and communities. A majority of participants (67%) agreed that going to public green spaces was a useful way to develop social connections with friends and neighbors. The desire to build social networks reflected the participants' values of being social. The participants were more likely to cluster in green spaces which were visited by other Chinese people. Two popular green spaces are shown in **Figures 5D,E**. **Figure 5D** and the interview responses indicated that older Chinese immigrants met their friends in the city parks on the Gold Coast, initially spontaneously and, thereafter, intentionally and regularly. They organized Chinese social groups in public green spaces and managed to participate in these social activities. The participants indicated how this increased positive feelings of well-being. With the increased number of Chinese immigrants interacting together in these spaces, the activities have increasingly gone beyond social function as the development of other group activities, such as Tai Chi, choir singing, and formed bands have also emerged. **Figure 5E** depicted a fishing spot favored by older Chinese immigrants. As stated by the participants, fishing, as an activity, encouraged them to meet and chat with each other as they exchanged fish and fish dish recipes and thus also enabled the participants to build social networks.

However, the participants perceived Gold Coast green spaces as places where certain barriers prevent their ability to conduct their preferred social activities. All (100%) the participants expressed the difficulties of interacting with their neighbors because of the language issue. They seldom start a conversation with their neighbors and often do not establish stable and deep relationships, as expressed by Xin (male, 76 years old, living in Australia for 9 years):

"I sometimes see some neighbors in the park. But we don't communicate much. It's annoying because I have many words to say but I can't express myself. I have learnt some simple sentences to communicate with them, but that's not enough. It's a pity that we don't have any in-depth communication."

Although they struggled to develop strong social networks, the interview confirmed that constantly visiting public green spaces helped these participants generate a sense of belonging to their place of residence. Within these green spaces, older Chinese immigrants have the opportunity to contact neighbors regularly, such as by greeting, smiling, or recognizing faces. Close to three-quarters of the participants (77%) expressed that, through this regular contact with their neighbors, they gradually developed an attachment to the neighborhoods, which positively influenced their well-being, as denoted by Dong (male, 67 years old, living in Australia for 4 years):

"I go to the nearby park every day, and I can see some familiar faces. They look very friendly and warm-hearted. They show me how to use fitness equipment; our dogs can play together. I feel very happy that I can live in that neighborhood. I feel I am a member of that place now."

Overall, values of older Chinese immigrants have been extracted from the interviews. Their perceptions of green spaces are informed by their values and therefore can have effects on their well-being.

DISCUSSION

With the aging population in urban areas becoming more diverse, a key issue in research, for urban planners, is how services and activities can be provided to residents with various needs in public green spaces. This study explores the diverse and complex interrelationship between green spaces, perception, well-being, and values among older Chinese immigrants in Australia. This paper utilizes a mixed method as it combines the use of travel diaries, mapping exercises, and interviews to draw data. This method identified patterns in the participants' interactions with green spaces and revealed their preferences in green spaces. As their preferred green spaces are clustered on the Gold Coast, poor accessibility was a barrier for older Chinese immigrants trying to engage with public green spaces. Their interaction with green spaces embodied their values of keeping healthy, having an active lifestyle, and fostering social connections. The concept and the design of urban green spaces on the Gold Coast impede older Chinese immigrants' ability to fully express their values, which then negatively influences their perceptions on green spaces.

First, the results from the travel diaries highlight the spatio-temporal patterns apparent in older Chinese immigrants' behavior and interaction with green spaces and physical activity. Older Chinese immigrants' willingness to visit green spaces at dusk may be attributed to a traditional belief in China, which suggests that taking a stroll after dinner is good for health (Cerin et al., 2013). These findings indicate the importance of managing green spaces to accommodate for use of the space during the night.

The poor lighting in residential areas creates insecure environments that impeded upon the participants' ability to walk in green spaces at night. Therefore, developing high-quality paved trails that are clearly lit would likely encourage older Chinese immigrants to maintain their active lifestyle, as this would enable them to feel secure and visit green spaces in the evening. For older Chinese immigrants who cannot walk independently and/or are unable to take public transport or drive, green spaces near their homes play a significant role in their ability to achieve their physical activity goals. This finding is also congruent with a previous study which found that urban green spaces can be especially significant for vulnerable groups (Maas et al., 2006). For people with mobility issues such as other immigrants, disabled residents, or people who suffer from mental health issues, public green parks, especially within their neighborhood, are key places that help to promote social networks and community engagement. Staff related to green spaces management therefore can play a positive role by helping minority groups access the major city parks where various activities are held. Improving the quality of walking tracks and illuminating the road could also help promote a sense of security when visiting green spaces. Public green spaces are important features for these vulnerable groups as these enable them to engage with their society. Therefore, when creating neighborhood governance policies, urban green spaces should be taken into consideration.

Second, older Chinese immigrants are more likely to visit urban green spaces either with their spouse or alone, but seldom with family. Older Chinese immigrants usually depend on the assistance of their adult children for transportation, shopping, and medical care (Guo et al., 2016). As a result, visiting green spaces can be seen as a means to fulfill their desire to conduct activities independently. Older Chinese immigrants often visit green spaces independently and enjoy their own leisure time, which requires green spaces to have high security. Limited mobility and safety concerns, such as worries about getting lost, can negatively influence their interaction with green spaces. Based on this finding, urban planners and green space managers should support residents who are frail or who have mobility limitations to enable them to visit green spaces more freely. Several strategies can be applied. One of these is to organize activities, with the help of public service organizations or immigrants' associations, to enhance the accessibility to the preferred activities of members of this group in these green spaces, and to help encourage older Chinese immigrants to feel positive about visiting green spaces. Another is to improve the sense of security in green spaces to encourage vulnerable residents to visit. This could be done through methods such as designing disability access and monitored green spaces with formal or informal surveillance. For those people who have mental health issues or language barriers, a sufficient sense of security encourages them to visit green spaces and ultimately benefit their health and well-being.

Green spaces were also important places for older Chinese immigrants as they helped to develop social networks, which then provided opportunities for them to perform traditional collective Chinese activities. However, difficulties in accessing these particular green spaces hindered their ability to participate in activities. In China, high-density urban development makes it possible for residents to walk or take public transportations to destinations. Older Chinese immigrants are used to walking to nearby green spaces to participate in activities. However, the urban traffic pattern in Australia heavily relies on private vehicles. On the Gold Coast, 88% of daily trips are made by cars, while only 7% of trips are by walking and the remaining 3% are by public transport (City of Gold Coast, 2013). Major thoroughfares and an abundance of canals serve as neighborhood boundaries. Large expanses of tract housing in suburban areas restrict the residents' ability to visit other parks in the city center or outside of their neighborhoods. Participants with lower mobility are limited to visit green spaces that are far from their home, only able to visit local-neighborhood green spaces. It can be deduced that the accessibility to infrastructures affects the travel routes and visitation to green spaces, which is closely related to the neighborhood type in which they live. With this in mind, further studies of how accessibility to green spaces in urban areas can be increased should be considered. With the number of immigrants increasing, collaborating with Chinese organizations to better understand the needs of these minority group members so that culturally sensitive planning can take place should be taken into account in future development and renovation plans for urban green spaces.

In 2014, the average neighborhood green space area in China was 12 m^2, compared to 154 m^2 in South East Queensland, Australia (Wang et al., 2015). Urban green spaces are also socially mediated ecologies, developing within a particular culture and social ideology. In Australia, green spaces differ from those in China by size, the ornamental plants, the design, and the facilities (Wang et al., 2015). These social, cultural, and ecological differences shape how older Chinese immigrants perceive and utilize green spaces (Byrne and Wolch, 2009). The results also find that participants are aware of the differences in the soundscape between the Gold Coast and their hometowns. The birdsongs mentioned in the interviews and the participants' described tranquil experiences in green spaces helped to form a soundscape for public green spaces (Liu et al., 2019b; Shu and Ma, 2020). Therefore, further studies are needed to investigate how the older immigrants perceive the soundscape and how different cultural factors affect their relationship with the soundscape in green spaces and their well-being. The green spaces present within this research are informed by western culture, which assumes that visitors focus on individualism and the quiet enjoyment of nature (Byrne and Wolch, 2009). Older Chinese immigrants, however, prefer lively environments of green spaces. The particular lifestyle and activities of older Chinese immigrants influence the way they express their values in relation to green spaces. Although they praise the landscape in green spaces and its physical benefits to their well-being, the participants had negative perceptions of green spaces because of their own cultural values, which resulted in diminished social and mental well-being. The benefit of approaching greenness is reduced when the green space cannot meet the values of residents. Therefore, in order to maximize the positive functions of green spaces for older Chinese immigrants, values held by this group should be firstly identified.

With regards to urban planning, although many previous studies call for inclusive urban planning for multicultural cities (Rishbeth, 2001), few strategies have been implemented into different measures and programs. With the increase of ethnic minority groups in urban areas, urban planners must also be sensitive to the significance of minority ethnic groups as a part of local society. For example, the voices of immigrants could be taken into consideration in the process of designing green spaces and city governance.

The limitations of this study also warrant a mention. First, the research recorded 30 interviewees' travel behaviors; therefore, their patterns of green space visitation may not be representative of a full picture that reflects all older Chinese immigrants' living conditions on the Gold Coast. However, the analysis of the interviews still offers great insight into older Chinese immigrants' perceptions of urban green spaces and the role that cultural values play in the relationship between green spaces and well-being. Regarding the participant recruitment process, all the participants were recruited through Chinese community centers; therefore, most of the participants were relatively healthy, active, and capable of participating in outdoor activities. The most vulnerable individuals who were less mobile were therefore underestimated. Second, this research treats the older Chinese immigrants as a homogeneous ethnic group and ignores the variety of their demographic characteristics, background, and living conditions in their hometowns. More explicit breakdowns could enable these factors to provide further insight into their interactions with green spaces after immigration. Third, this study only discusses the values of older Chinese immigrants in order to construct an inclusive urban green space; however, future studies could compare the experiences of older Australians and other older minorities. Finally, this research only focuses on parks and ignores other types of greenness in urban areas such as the green spaces along the road or surrounding homes and the private green spaces within the participants' houses.

CONCLUSION

This research examines identifiable patterns pertaining to green space visitation, with specific focus on older Chinese immigrants and the relationship between green spaces and their well-being on the Gold Coast. The results indicate that green spaces maintained the well-being of older Chinese immigrants. For older Chinese immigrants, Chinese-related activities significantly influence their perceptions of green spaces. However, the preferences for activities and a lack of accessibility to green spaces also negatively influenced older Chinese immigrants' ability to perform their values of keeping healthy, being social, and being engaged. The fact that the values of older Chinese immigrants are less fulfilled in green spaces on the Gold Coast indicates a contradiction among green space provisions, demand, and utilization. The findings highlight the importance of activity management and multicultural planning and design of urban green spaces.

This study adopted a mixed method combining the travel diary, mapping travel routes, and in-depth interviews to understand the participants' behavior and experiences. The mixed method helped compensate for independent methodological weaknesses. The travel diary and the mapping exercise aided in the visualization of the participants' travel routes and provided a window of insight into everyday situations and interactions that occur within green spaces. The combination of interviews strengthened the understanding of the ways in which participants experience green spaces and the meaning and functions that drive their motivation to conduct certain activities in green spaces. The participants revealed dimensions of their social context that influenced their sense of well-being when they visited green spaces, such as the language barriers and experiences of stress that stem from insecurity.

This study highlights how values play a crucial role in how the relationship between green spaces and well-being is understood. The theory of value provides urban planners and policymakers with a better understanding of which elements of the urban environment are important to residents and therefore helps to shape priorities for policy and maximize the benefits of environments. Cultural variation should be taken into account during the decision-making process, which requires participatory or interactive planning and management between residents and urban planner. Green space planning and management should contribute to green spaces with serious consideration of the physical and social needs and expectations of vulnerable groups and residents with diversified values.

This research sheds light on the accessibility of urban green spaces and the provisions that enable age-friendly community planning. Increasing accessibilities of various levels of green spaces, especially for those who organize cultural activities, could significantly increase the benefits of those green spaces. It also needs to be mentioned that the implications of this research are not just for older Chinese immigrants but also for other vulnerable groups who are not being effectively served by urban parks. Immigration and the aging population have altered the demographic compositions in urban areas, which had resulted in complex demands being sought in urban green spaces. When considering the increasing number of older people and the ethnic minority groups, their preferences in recreational activities and their social needs should be considered in future urban green space planning. More attention should be given to cultural elements and facilities that promote exercise and social networks within the provisions and design of green spaces. Intensifying culturally sensitive strategies in urban planning and design is important. For a long-term policy, being sensitive to the values of residents is necessary for urban planners if they wish to develop more appropriate facilities that meet the needs of those living within a dynamic demographic structure.

DATA AVAILABILITY STATEMENT

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by Griffith University Human Research Ethics Committee. The ethics committee waived the requirement of written informed consent for participation.

AUTHOR CONTRIBUTIONS

SG contributed by designing the manuscript, map designing, and structuring and writing the manuscript. CB and KD contributed by reviewing and editing the manuscript and supervision and project administration. All authors contributed to the article and approved the submitted version.

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Effect of Urban Greening on Incremental $PM_{2.5}$ Concentration During Peak Hours

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In China, severe haze is a major public health concern affecting residents' health and well-being. This study used hourly air quality monitoring data from 285 cities in China to analyze the effect of green coverage (GC) and other economic variables on the incremental $PM_{2.5}$ concentration ($\Delta PM_{2.5}$) during peak hours. To detect possible non-linear and interaction effect between predictive variables, a kernel-based regularized least squares (KRLS) model was used for empirical analysis. The results show that there was considerable heterogeneity between cities regarding marginal effect of GC on $\Delta PM_{2.5}$, which could potentially be explained by different seasons, latitude, urban maintenance expenditure (UE), real GDP per capita (PG), and population density (PD). Also described in this study, in cities with high UE, the growth of GC, PG, and PD always remain a positive impact on mitigation of haze pollution. This shows that government expenditure on urban maintenance can reduce or mitigate the environmental pollution from economic development. In addition, the influence of other urban elements on air quality had also been analyzed so that different combinations of mitigation policies are proposed for different regions in this study to meet the mitigation targets.

Keywords: green coverage, $PM_{2.5}$, threshold model, kernel-based regularized least squares model, urban maintaining expenditure

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INTRODUCTION

With the rapid urbanization and economic development, urban greening has become an urban livability standard and important symbol of residents' well-being (1). How to achieve a win-win situation for environmental protection and urban development has long been controversial for policymakers (2). Especially for rapidly-developing countries such as China and India, where rapid urbanization and deteriorating air quality is increasingly threatening the well-being of urban residents (3), also increasingly demanded for urban planning, policy, and management.

Over the past decades, numerous studies have highlighted the contribution of urban greening in the achievement of improved air quality, on the basis that pollutants deposit more efficiently onto vegetation (4–6). In a study of broad-scale estimates of $PM_{2.5}$ removal by trees from 10 American cities, substantial health improvements and economic value produced by urban trees have been found (4). In a comparative study in sample cities in China and United States, the authors pointed out that increasing forest coverage of cities through urban greening and afforestation should be a prioritized strategy to mitigate $PM_{2.5}$ pollution, and it was argued, relative to American cities, it was more important for the densely populated and rapidly expanding urban areas in eastern China to increase the intermixing of forest and urban land through polycentric urban development (7).

At a finer spatial scale, a series of methods and tools, such as remote sensing (8–10), field measurements (11–13), Geographical Information Systems (GIS) (10), and landscape analysis software (8), had been used for analyzing urban morphology (building layout, road patterns, land uses, and green space) and its relationship to haze pollution, aims at reducing $PM_{2.5}$ concentrations and minimizing human exposure to particulate matter. A study conducted in the United Kingdom showed that green infrastructures are beneficial but they do not represent a solution to completely remove air pollution from cities, while working on removing street pollution via dispersion proved to be as or even more efficient than deposition technologies (12). In the same article, it was also suggested that areas with leafless period need to consider different reduction in $PM_{2.5}$ caused by seasonal factors like urban greening. In addition, other scholars had also highlighted that pollutant concentration (8, 9, 14) and wind speed (9) should also be considered synthetically since the marginal benefit of urban green coverage on air quality improvement is not always positive under the influence of these factors. In a urban-based panel study, the overall findings support higher density as opposed to lower density urban development in China while higher density does reduce a city's urban park and green space (per capita) (15). The above-mentioned research led us to focus on the necessity of whether urban greening being coordinated with population density, economic growth and other urban elements.

In addition to urban physical elements, there are also studies that attempt to explain the impact of development strategy of cities and policies on air quality. Most empirical studies on this topic have shown that there is a complicated relationship between environmental pollution and the level of socioeconomic development (7, 14, 16, 17). Using panel threshold model, Xiao had revealed the existence of an inverted U-shaped relationship between environmental regulations and $PM_{2.5}$ emissions among 30 OECD countries (16), clearly indicating the importance to develop environmental management and policies in line with the stage of economic development. In contrast to Xiao, Kui argued that haze pollution is a problem derived from the mode of economic development rather than economic development overall, in an empirical study conducted in China, and pointed out that the impact of urbanization varies across regions; while promoting urbanization will be conducive to decreased $PM_{2.5}$ concentrations in Northwest China and Northeast China, it will contribute to increased $PM_{2.5}$ concentrations in other regions (14).

In recent years, spatial analysis or econometric methods have been wildly used in research on influencing factors of urban air quality (18–21), Innovative methods such as multi-scale geographically weighted regression (MGER) (22), semi-parametric global vector autoregressive model (SGVAR) (23) have emerged recently. The spatial effect of haze pollution is becoming an important topic in this field (24, 25).

Previous studies have confirmed the complex correlation between urban greening and haze pollution, but the empirical analysis is still lagging. First, studies have shown that urban air quality is the result of the complex interaction of greening (4, 8, 12, 18), urban form (7, 10, 15), socioeconomic characteristics (11, 14, 19, 20), and regional patterns of development (14, 16), any attempt to statistically assess the correlation between greening coverage and haze pollution will be complicated by a series of confounding factors' variation over time and space, making it difficult to draw general conclusions (7, 24). Distinctive findings in various regions have confused the relationship between greening coverage and air pollution, and the potential of changing air pollution by increasing greening coverage from the perspective of urban planning is still uncertain. Secondly, in the study of horizontal comparison of multiple cities with background $PM_{2.5}$ concentration as the research object, meteorology and activities related to anthropogenic emission are usually the main influencing factors, and few studies directly focus on the effect of greening coverage on air quality. Therefore, more detailed timing data (especially during peak periods) are needed to reflect the improvement of haze pollution by urban greening. Third, studies at different spatial scales have revealed that the effect of green cover on $PM_{2.5}$ concentrations is not a simple linear relationship, which influenced by many other factors such as regional development patterns (14, 16), urban compactness (14, 15), background $PM_{2.5}$ concentrations, vegetation types, wind speed, etc., but the specific proportional relationship between them remains unclear.

This study set out to explore the contribution of green cover and other elements to reduce haze pollution, and further to evaluate the roles of these elements in terms of both singular and interacting behaviors. Those results would be helpful to formulate effective strategies for improving the urban atmosphere environment. To that end, we use ground-level $PM_{2.5}$ data during peak hours in 285 cities in China, which had been undertaken to eliminate regional background concentration. Besides, people were most exposed and vulnerable to haze pollution during peak hours, indicating that the potential health benefits of reducing ambient $PM_{2.5}$ was credible. In addition to adding environmental and urban characteristics as control variable, the model also considers variations in the direction and intensity of each driver in different contexts, such as season, latitude (in consideration of the difference in terrain, climate and variation in vegetation composition caused by 32°N latitude limit), government expenditure (for urban maintenance), etc. Finally, to capture the compounding effects of urban physical parameters on $PM_{2.5}$, the kernel-based regularized least squares (KRLS) model was adopted to consider possible interactions among variables.

As of late, numerous methods were reported to characterize the effect of air quality factors varying along different spatial distribution and conditional distribution such as local linear method (23), geographically weighted regression (GWR) (25), quantile regression (26). The kernel-based regularized least squares (KRLS) algorithms have notable advantages over conventional statistical models. Kernel functions, which provide a measure of similarity between the covariate vectors of two observations as basic functions, complex relationship

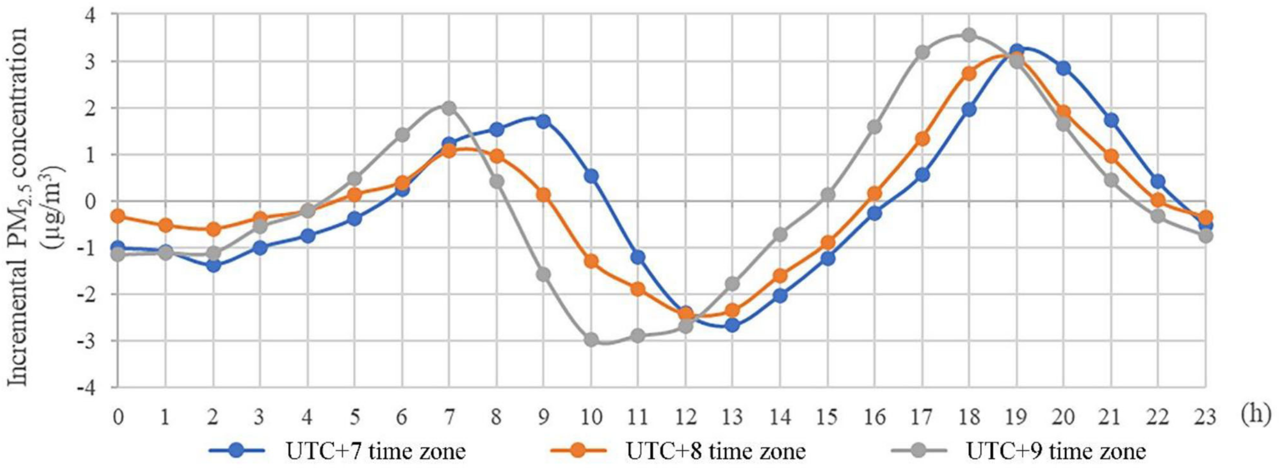

FIGURE 1 | Diurnal variation of $PM_{2.5}$ concentration in different time zones. Karamay and Urumqi, the only two cities in UTC+6 time zone are not considered.

between dependent variable and independent variable vector, will be translated into a linear combination of these basis functions, thus providing closed-form estimates for the predicted values, variances, and the pointwise partial derivatives that characterize the marginal effects of each independent variable at each data point in the covariate space (27). Therefore, with KRLS analysis, it becomes feasible to capture possible non-linearities, interactions, and heterogeneous effects of factors on mitigation of haze pollution in different cities, consequently, to set corresponding governance measures according to the socioeconomic environment and pollution characteristics in different regions.

RESEARCH DESIGN

Dependent Variable: $PM_{2.5}$ Data

The ground-level $PM_{2.5}$ data adopted in this study have covered 285 cities in China (1,534 weather stations in total, evenly distributed in the built area), published hourly by China National Environmental Monitoring Center[1], from 1 June 2017 to 31 May 2018.

Related studies have found that the $PM_{2.5}$ contribution of transportation to average mass concentration can be 25–50% (28–30), other sources also include industrial activities (including electricity generation, industrial fuels) (31, 32), coal burning and biomass combustion for cooking (33), winter heating (34), construction (35), and other specific activities (setting off fireworks & open straw burning) (36, 37). Any attempt to statistically evaluate the strength of association between urban elements and $PM_{2.5}$ pollution will be complicated by a range of confounding factors (7), thus data screening should be undertaken in studies of daily $PM_{2.5}$ concentrations to screen for specific pollution events (11, 13, 38).

Figure 1 shows the distribution of $PM_{2.5}$ concentration increase per hour from UTC+7 time zone to UTC+9 time zone for a total of 283 cities (Karamay and Urumqi, the only two cities in UTC+6 time zone are not considered) (The detailed average hourly trends of $PM_{2.5}$ concentration in each city are shown in **Figure S1**). In most cities, $PM_{2.5}$ concentration exhibits a bimodal pattern of changing rhythms, peaking around dawn and dusk, relatively stable at night. Due to the difference in urban morphology (urban size, road conditions, etc.) and time zones, the start time and duration of the increase of particulate matter were different, complex formulas were therefore needed to ensure that the maintenance duration and intensity of the increase in $PM_{2.5}$ concentrations from mobile source are accounted for [considering that the hazard intensity of haze pollution depended on its concentration and exposure time (39–41)]. Then, $PM_{2.5}$ concentration changes from 4:00 to 10:00 a.m. were selected for comparison in this study. These values were converted to $\mu g/m^3$ and expressed herein as ΔPM.

$$\Delta PM_i = \sum_{t=4}^{10} P_i^t \times I(P_i^t) \quad (1)$$

$$I(P_i^t) = \begin{cases} 0, & P_i^t \le M \\ 1, & P_i^t > M \end{cases} \quad (2)$$

Where i = (1, ... , N) represents the city number, P_i^t is the variable quantity of $PM_{2.5}$ concentration per hour (calculated as 0 if the amount of change is negative), I( ) is an indicative function, M is the median of $PM_{2.5}$ concentration per hour in the city i from 4:00 to 10:00 a.m.

The advantages and limitations of such data processing method further explored in the Discussion. The peak period in the morning rather than in the evening was chosen due to, first, commuting activities are relatively single and fixed human activities during the period, which ensure the comparability between regions, while afternoon commutes in parts of China are affected by seasonal changes. Furthermore, $PM_{2.5}$ concentration tends to a source/sink balance at dawn, ensuring a relatively consistent initial state.

[1]http://106.37.208.233:20035/

TABLE 1 | Data source of variables.

Variables	Definition	Mean	S.D.	Data source
$\Delta PM_{2.5}$	Incremental $PM_{2.5}$ concentration from 4:00 a.m. to 10:00 a.m. ($\mu g/m^3$)	4.11	3.532	China Environmental Monitoring Station
GC	Green coverage per capita in municipal districts (m^2)	15.25	13.055	China Urban Statistical Yearbook 2018
PD	Population density in municipal districts (pop/km^2)	399.33	314.736	CEIC China economic database/Cathay Pacific Database
PG	Real GDP per capita in municipal districts (RMB)	69740.36	35119.019	China Urban Statistical Yearbook 2018
IE	Industrial soot (dust) emissions in municipal districts (tons)	18268.57	22337.091	China Urban Statistical Yearbook 2018
HU	Annual air humidity (%)	68.23	10.751	National Climatic Data Center
UE	The ratio of urban maintenance expenditure to GDP (1 = over 5%, 0 =below 5%)	0.239	-	China Urban Statistical Yearbook 2018
N/S	Whether at north of Qinling-Huaihe line (1 = 32°N North, 0 =32°N South)	0.526	-	CEIC China economic database

Independent Variables: Socio-Economic Data

Sources of variables used in this study were as follows: China Urban Statistical Yearbook 2018, CEIC China Economic Database, Cathay Pacific Database, National Climatic Data Center[2]. For the missing values in some existing data sets, they are replaced by the corresponding means.

Prior to analysis, all variables were screened by backward elimination statistical procedure, the final model retained five independent variables: (1) Urban green space is a key factor affecting the health and quality of life of urban ecosystem. Local governments in China tend to plant trees rather than build parks to ensure the supply of public goods for urban greening (41). Green space is a kind of non-competitive urban public amenities. To highlight the environmental pressure caused by urban overcrowding, the green coverage per capita (GC) in built-up areas is used to measure the level of urban greening. (2) Within the spectrum of city sizes there are enormous differences in population size, built-up area, and industrial structure. Accordingly, real GDP per capita (PG) is chosen to measure the level of economic development of a region. (3) Increased population density due to urbanization usually leads to increased environmental pressure. Since there are also suggestions in the literature that urban density promotes green travel (reducing gasoline consumption, increasing bicycle use) and thus reduces regional air pollution levels (15, 42), population density (PD) is used replacing urbanization as the main explanatory variable to determine the impact of population density on haze pollution. (4) China's industrial sector consumes far more energy than other sectors and fossil fuel combustion and industrial soot emissions from the secondary industry as well as building dust are important causes of haze pollution (43, 44), thus industrial soot (dust) emissions (IE) is chosen to measure the contribution of industrial production processes to haze pollution. (5) Climatic conditions are key variables affecting the rate of tree deposition, higher air humidity increases $PM_{2.5}$ moisture content, which contributes to the $PM_{2.5}$ settlement in time (5). Therefore, the average annual air humidity of each region is included in the explanatory variables.

TABLE 2 | Backward stepwise regression model.

Variables	Coef.	Std. Err.	*t*	*P*>*t*	VIF
HU	−1.981	0.333	−5.960	0.000	1.67
PG	−0.345	0.120	−2.890	0.004	1.56
PD	−0.125	0.060	−2.070	0.039	1.43
GC	−0.144	0.078	−1.840	0.067	1.35
IE	0.078	0.046	1.680	0.094	1.16

Variables were previously logarithmized.

China covers many degrees of latitude, with complicated terrain and radical variations in climate, which produces significant variation in north-south vegetation composition. For the final model, we also added a vegetation-type dummy variable N/S in order to control for season-variant fixed effects such that each city was assigned a value of 1 (deciduous vegetation) or 0 (evergreen vegetation) according to whether it was or was not at north of 32°N latitude limit, well-known as the so-called Qinling-Huaihe line (around 32° N in the eastern part of China), which is also the generally accepted boundary line of heating (45).

The primary goal of our study was to understand the effects of greening in particular on mitigation of haze pollution during peak hours. Previous studies have typically examined the impact of government expenditure on air quality from the perspective of pollution control such as energy use and production structure (46), neglected the possibility that urban maintenance expenditure could have a beneficial impact on air quality improvement by expanding the share of greening reward to reduce air pollution. Then, a dummy covariate UE is added to distinguish cities with high-level expenditure (UE assigned as 1) and low-level expenditure (UE assigned as 0) in urban maintenance, which can help determine if government urban maintenance efforts will work best for environmental benefits of greening.

Variable descriptions are in **Table 1**. The result of backward stepwise regression model is presented in **Table 2.**

[2] ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-lite/

Threshold Regression

Threshold model is the basis for developing more complex ones. Therefore, in this study, a threshold model has been applied to explore the non-linear relationship between green coverage and $PM_{2.5}$ concentrations, with refinements and extensions of this model being presented in the following descriptions.

$$y_i = \beta_1 X_i \times I\left(q_i \le \gamma\right) + \beta_2 X_i \times I\left(q_i > \gamma\right) + \varepsilon_i \tag{3}$$

y_i is the response variable, X_i is the explanatory variable matrix, β is the coefficient matrix, q_i is the threshold variable, γ is the threshold value to be estimated, and $I(\cdot)$ is the indicative function (while $q_i \le \gamma$, $I(q_i \le \gamma) = 1$, $I(q_i > \gamma) = 0$, while $q_i > \gamma$, $I(q_i \le \gamma) = 0$, $I(q_i > \gamma) = 1$), ε_i is the error term.

The arbitrary value of q_i is taken as threshold value for regression of formula (3), and $\hat{\gamma}$ is defined as the estimated threshold value. Therefore, the more approximate the value q_i to the real threshold value $\hat{\gamma}$, the smaller the sum of squares for residuals (SSR) of the model. By carrying out point-by-point regression, it is obtained that when $SSR(\hat{\gamma})$ is the minimum, $\hat{\gamma}$ is the estimated threshold value, namely, $\hat{\gamma} = argminSSR(\hat{\gamma})$. The important step of threshold regression also includes the determination of the number of threshold value. Generally, Grid Search is used to determine other threshold value that can minimize the sum of squares for residuals. The threshold regression also needs to solve the validity of threshold value. By constructing the maximum likelihood function, the significance and validity tests are carried out. It is assumed that the null hypothesis H_0 of test is $\theta_1 = \theta_2$ and the alternative hypothesis is $\theta_1 \neq \theta_2$. Under the conditions of null hypothesis, the sum of squares for residuals of model regression result is recorded as S_0. Therefore, the statistical magnitude of likelihood test is $LR = [S_0 - S(\hat{\gamma})]/\hat{\sigma}^2$. At the same time, with the help of Bootstrap, the asymptotically-efficient interval of LR is obtained. The confidence level is set as α. When $LR \le -2\log(1-\sqrt{1-\alpha})$, the null hypothesis is established, which indicates that the model has the threshold effect. In practical application, there may be double threshold or multiple threshold cases, and the double threshold or multiple threshold value can be searched by using similar methods. This study uses several variables to calculate the threshold value for the same sample and selects the optimal variable as the threshold variable according to its significance.

This model referred to the reference model proposed by Hansen (47), the detailed rationale of the model can be found in his paper.

Kernel Regularized Least Squares (KRLS)

Kernel Regularized Least Squares Model (KRLS) is a machine learning method described in the article by Hainmueller and Hazlett (48), designed to solve regression and classification problems in social science modeling without relying on linear or the additivity hypothesis, allowing interpretation in a manner similar to a generalized linear model, while also allowing the marginal effect of each independent variable in the variable space to be derived. Specific steps are as follows.

Kernel Function

Assume a set of observations in the form of (y_i, x_i), where $i = 1, \ldots, N$ indexes the observations,$y_i \in R$ is the outcome of interest, $x_i \in R^D$, RD is the set of independent variables x_i (x_i can be regarded as a vector composed of D-dimensional variables), using a symmetric, positive definite Gaussian kernel function to measure similarity between the covariate vectors of two observations:

$$k(x_j, x_i) = \exp\left(-\frac{\| x_i - x_j \|^2}{\sigma^2}\right) \tag{4}$$

Where $\| x_i - x_j \|^2$ is the Euclidean distance between the independent variables xi and xj, $\sigma^2 \in R^+$ is the bandwidth of kernel function.

Imagine we have some test-point x^* at which we would like to evaluate the function value, then the predicted value y^* is given by

$$y^* = f(x^*) = \sum_{i=1}^{N} c_i k(x^*, x_i) \tag{5}$$

Where the objective function $f(x^*)$ is regarded as a linear combination of several kernel functions $k(x^*, x_i)$, and c_i is a weight for each covariate vector.

Since $k(x^*, x_i)$ is a measure of the similarity between x^* and x_i, we see that the value of $k(x^*, x_i)$ will grow larger as we move the test-point x^* closer to x_i. In other words, the predicted outcome at the test point is given by a weighted sum of how similar the test point is to each observation in the (training) dataset. It is inferred that, similar to the principle of the generalized linear model, we can use a set of kernel functions that describe the similarity of the sample observations to replace the natural measure of the data, that is, for any independent variable x, there should be a weight vector ci(i = 1, ..., N), allowing a linear fitting function of the mathematical expected value of the dependent variable to be constructed based on the similarity of the independent variable x to the observed value:

$$y = f(x) = \sum_{i=1}^{N} c_i k(x, x_i) \tag{6}$$

Applying the Equation (6) to each data set, the model can be rewritten in vector form as:

$$y = Kc = \begin{bmatrix} k(x_1, x_1) & k(x_1, x_2) & \cdots & k(x_1, x_N) \\ k(x_2, x_1) & \ddots & & \\ \vdots & & & \\ k(x_N, x_1) & & & k(x_N, x_N) \end{bmatrix} \begin{bmatrix} c_1 \\ c_2 \\ \vdots \\ c_N \end{bmatrix} \tag{7}$$

In this form, the KRLS model can be viewed as a linear system, the output matrix is a vector of expected values of all dependent variables, with N × N matrix K containing all kernel functions measuring the similarity of observations.

Regularization

To find the only approximate solution of Equation (7), with perfect fit being sought by choosing $\hat{c} = K^{-1}y$, it is necessary to control model's fitting bias and complexity at the same time. Therefore, we minimize the model fitting bias and add a penalty term of complexity to construct the objective function:

$$\underset{f\in H}{argmin} \sum_i (V(y_i, f(x_i))) + \lambda R(f) \quad (8)$$

Where $V[y_i, f(x_i)]$ is a loss function that measures the estimated error at each observation, $R(f)$ is a regular term that measures the complexity of the model, and $\lambda \in R$ is a control parameter determining the tradeoff between model fit and complexity. H is the "hypothesis space" formed by all possible functions.

To solve the minimization problem of objective function, the least square method is used to measure the model's variance loss $V[y_i, f(x_i)]$, and the Tikhonov regularization method is used to construct complexity penalty $R(f)$, optimization of objective function in Equation (8) can be expressed as:

$$\sum_i (V(y_i, f(x_i))) = \sum_i ((f(x_i) - y_i)^2 = (y - Kc)^T (y - Kc) \quad (9)$$

$$R(f) = \| f \|_k^2 = \sum_i \sum_j c_i c_j k(x_i, x_j) = c^T kc \quad (10)$$

$$\underset{c\in R^D}{argmin} (y - Kc)^T (y - Kc) + \lambda c^T Kc \quad (11)$$

$$c^* = (K + \lambda I)^{-1} y \quad (12)$$

For the kernel bandwidth σ^2, referring to the method of Hainmueller and Hazlett (48), The default kernel bandwidth σ^2 is half the average Euclidean distance between the observations after normalization, such that set $\sigma^2 = D = \frac{1}{2}E[\| x_j - x_i \|^2]$. For the regularization parameter λ, the leave-one-out (LOO) strategy was used to calculates the sum of N observation variances, for any value of λ, and finds the optimal solution of λ by minimizing it (48).

Equation (11) reveals that when the kernel function window width σ^2 and the regularization parameter λ are fixed, there is $c^* \in R^D$ such that $y^* = Kc^*$ is the best linear fit of the conditional expectation function $E[y|x, \lambda, \sigma]$. The objective function is differentiated to obtain the optimal solution c of independent weights [Equation (12)]. It should be noted that for each data set in K, the process of generating the independent variable weight c is similar to the linear solution of the mathematical expectation of the dependent variable in the similarity of the sample observations in the fixed function window width, so any independent variable has its corresponding weight c.

Partial Derivative Estimation

Assuming that $X = (x^1, \ldots x^d, \ldots x^D)$ is a data set composed of N D-dimensional independent variables, according to Equation (8), any given sample j can be calculated to correspond to the d-dimensional independent variable partial derivative of the objective function:

$$\frac{\partial \hat{y}}{\partial x_j^d} = \frac{-2}{\sigma^2} \sum_i c_i \exp(-\frac{\| x_i - x_j \|^2}{\sigma^2})(x_i^d - x_j^d) \quad (13)$$

By calculating the point-by-point partial derivative of the d-dimensional independent variable, the average marginal influence of the d-dimensional independent variable on the dependent variable can be obtained

$$E_N(\frac{\partial \hat{y}}{\partial x_j^d}) = \frac{-2}{\sigma^2 N} \sum_j \sum_i c_i \exp(-\frac{\| x_i - x_j \|^2}{\sigma^2})(x_i^d - x_j^d). \quad (14)$$

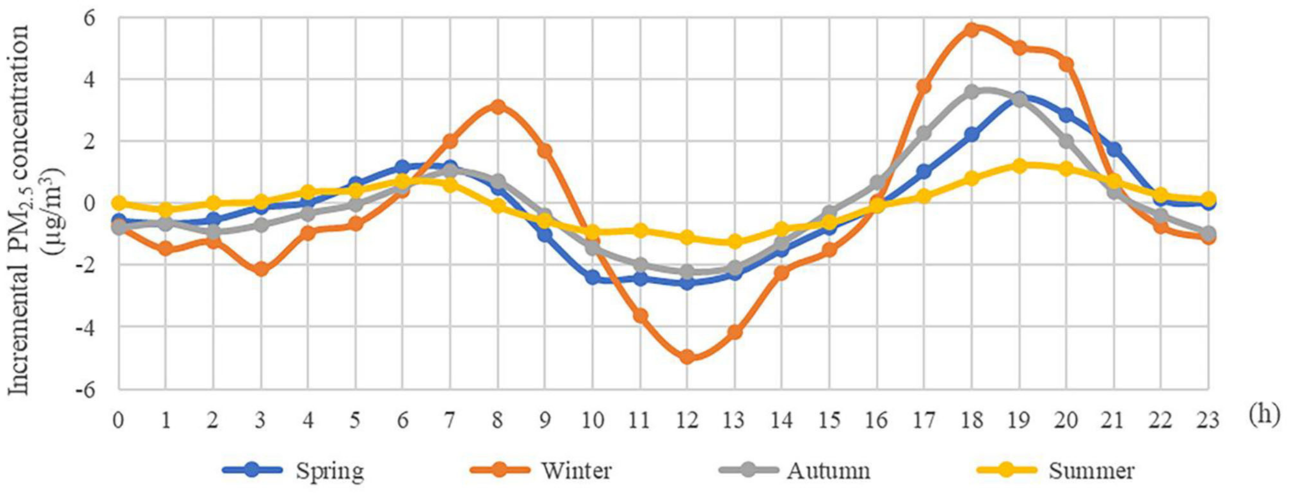

FIGURE 2 | Diurnal variation of $PM_{2.5}$ concentration in different seasons.

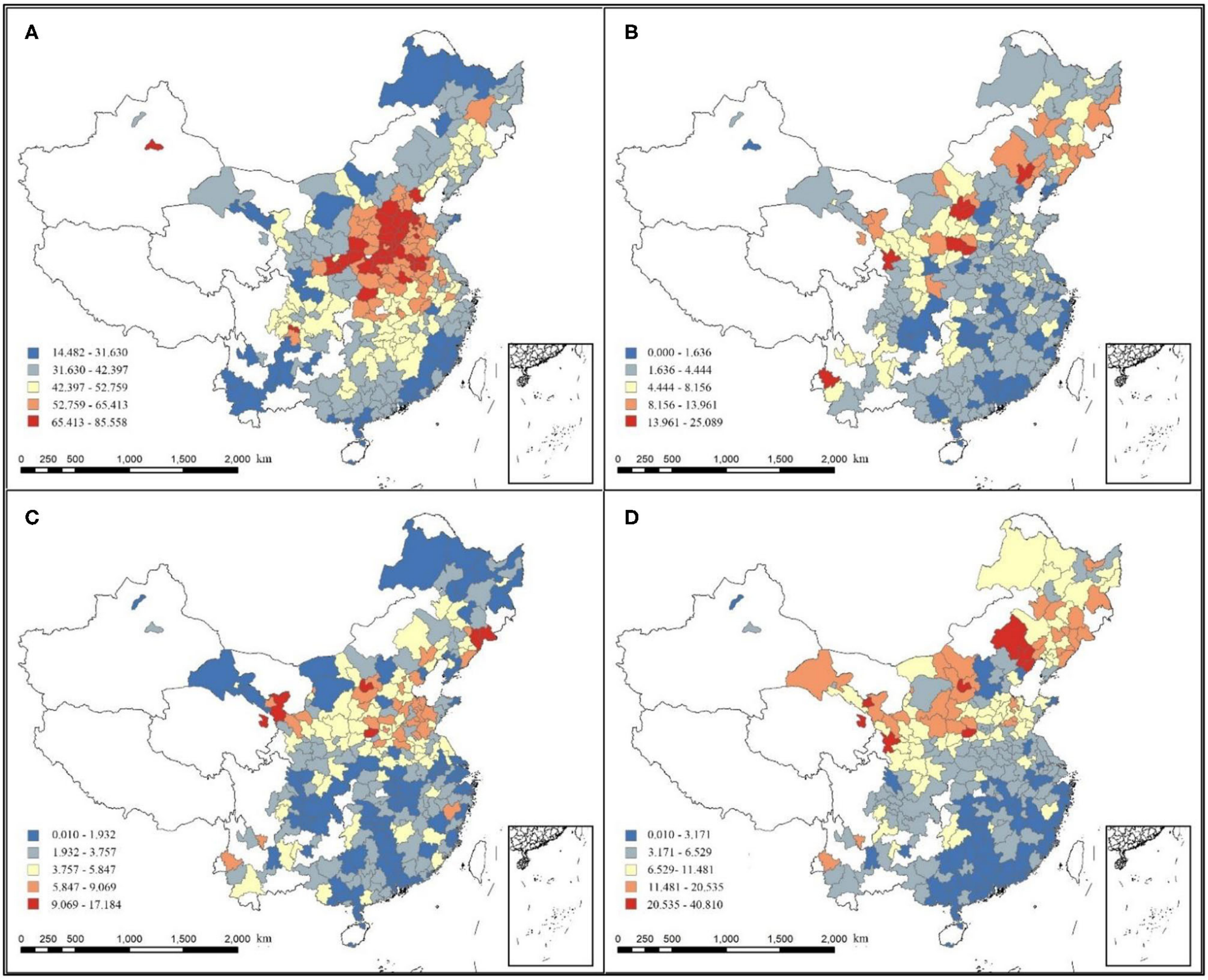

FIGURE 3 | Concentration spatial patterns of: **(A)** Average annual $PM_{2.5}$ concentration; **(B)** Annual incremental $PM_{2.5}$ concentration; **(C)** Incremental $PM_{2.5}$ concentration in summer; **(D)** Incremental $PM_{2.5}$ concentration in winter.

RESULTS

Particulate Matter Mass Concentrations and Spatial-Temporal Characteristics

Evident seasonal variations of $\Delta PM_{2.5}$ concentration increment in 285 cities are illustrated in **Figure 2**. We found that the amount of growth in $PM_{2.5}$ was significantly higher in winter than leaf-period, which demonstrates the necessity of building different models to capture spatiotemporal trends.

Figure 3 presents the space distribution of $PM_{2.5}$ and $\Delta PM_{2.5}$ in all 285 sample cities, which were categorized into five based on Jenks natural breaks. As shown in **Figure 3**, most of the severe haze pollution was concentrated in plain area of central China. The regions with high $\Delta PM_{2.5}$ were distributed mainly in north China and the regions with low $\Delta PM_{2.5}$ were distributed mainly in south China, with areas above 32° N experiencing a higher $\Delta PM_{2.5}$ in summer than in winter. We can see that a far greater impact on $\Delta PM_{2.5}$ is due to changes in season but not spatial spillover effect.

What needs illustration is that, in most cities, the diurnal variations of $PM_{2.5}$ concentrations were largely consistent and showed a bimodal pattern. In summer and winter, no increase in $PM_{2.5}$ concentration was detected in four cities during peak hours (in summer: Zhangjiakou, Changsha; in winter: Baoding, Chaozhou). Among them, Zhangjiakou and Changsha belong to Hebei, one of the provinces with the most severe haze pollution in China, not ruling out the possibility that the nighttime factory emissions wiped out the $PM_{2.5}$ increase that should had occurred in the morning. Since it needs to use the logarithmic form of observed value for model calculation, we used 0.01 (minimum value) instead for cities without $PM_{2.5}$ increase.

Regression Results of Threshold Model

A logarithmic version of Hansen's threshold model was estimated using different threshold variables. **Table 3** shows the results of

TABLE 3 | Test of threshold effect.

Dependent variable	Threshold variable	*P*-values	Threshold values	95% confidence interval
$\Delta PM_{2.5}$	Urban resident population	0.016	640.22	[574.3,683.064]
	Population density	0.010	391	[97.06,462]
	Proportion of secondary industries	0.184		
	Proportion of tertiary industries	0.384		
	Real GDP per capita	0.564		
	Urban Resident Population ≤ 640.22	0.03	220.18	[168.3,290.69]
	Urban Resident Population > 640.22	0.838		
	Population density ≤ 391	0.044	165.78	[97.06,200]
	Population density > 391	0.690		

the threshold effect tests. Two variables included the threshold effect are significant at the 10% level. We therefore found two threshold effects at the 5% significance level are found in both two variables in further detection. When urban resident population was set as the threshold variable, the threshold values obtained were 220.18 and 640.22. When population density was set as the threshold variable, the threshold values obtained were 165.78 and 391. As the best way to form confidence intervals for threshold is to form "no-rejection region" using the likelihood-ratio (LR) statistic for tests on threshold estimates, we plot the LR statistic (**Figure 4**) to display the threshold confidence intervals.

Table 4 presents the effects greening coverage and other factors on $\Delta PM_{2.5}$ by using threshold regressions. As the results show, green coverage in cities with low population size had a positive effect on $PM_{2.5}$ at 1% significance level, with a coefficient of −0.344, while no significant correlation was found in the cities of medium and higher population size (Urban resident population >220.18 million). In models with population density as threshold variable, cities with medium population density size was negatively correlated with GC at 1% significance level with a coefficient of −0.443. This means that, for countries with low population (column I) or medium population density size (column V), a 1% increase in green coverage caused a 0.3∼0.4% reduction in $\Delta PM_{2.5}$ concentrations. Despite the significant negative correlation observed in both column I and column V between GC and $\Delta PM_{2.5}$, cities in two columns are non-coplanar in space (**Figure 5**). This translates into omissions in threshold regression models, a diverse set of non-regular regression models that all depend on specific individual threshold, but a one-threshold model is the basis for developing more complex ones.

Population density was positively correlated with $\Delta PM_{2.5}$ concentrations at 1% significance level, suggesting that an increased population density in low density cities could contribute to the increase of air pollution. PG showed a weak negative association with $PM_{2.5}$ concentration in column II, while becoming negative at the 1% significance level in column VI. This indicates that economic growth has obviously positive effect on the mitigation of air pollution in high density cities (population density > 391 pop/km^2), while the same but weak impact exists in medium-sized cities (220.18 < Urban resident population <= 640.22). Moreover, there was a significant relationship between dummy variable N/S and $\Delta PM_{2.5}$.

Regression Results of KRLS Model

The preceding analyses indicated that the effects of green cover and other factors on $\Delta PM_{2.5}$ are not simply linear. Urban resident population threshold is likely evolved from different stages of urban development and economic scale; population density threshold is likely derived from land-sea gradients and latitudinal position. In this context, several sub-objectives were set up and validated by KRLS model to provide reference for urban planners, i.e.,

- To investigate the heterogeneity in the marginal effects of greening on $\Delta PM_{2.5}$ at different levels of socio-economic variables.
- What effect does government's strong/weak support for environmental protection have on haze pollution control?
- Can we find trajectories of drivers like EKC theory in relationships between $\Delta PM_{2.5}$ and other economic variables?

Traditional OLS regression was conducted along with the KRLS analysis to compare the two statistical approaches (**Table 5**). Unlike OLS analysis, which presents a constant marginal effect assumption, the KRLS model presents pointwise marginal coefficients for each sample case; therefore, it is possible to observe whether the influence of a given predictor on $\Delta PM_{2.5}$ varies with data points. Thus, when the marginal effects are heterogeneous, KRLS results may be informative.

Table 5 shows that GC has a positive impact on motivation, the result was significant at the 10 and 5% level in the whole year and winter respectively but not significant in leaf-less period. Considering that deposition of deciduous vegetation on $PM_{2.5}$ in winter may decrease, a further understanding of the interaction between GC and $\Delta PM_{2.5}$ is required. The positive correlation between N/S and CR was detected in both statistical models, suggesting that it is reasonable to investigate the effect of urban green cover on air quality in the north and south of Qinling-Huaihe line, which would however require a different isolation protocol.

We also found relationships between economic variable (DE & PG) and $\Delta PM_{2.5}$. The significant negative correlation between DE and $\Delta PM_{2.5}$ was detected in both statistical models, suggesting that relatively compact urban landscape may be an effective strategy to relieve morning air pollution from human economic activity. PG values also exhibited weakly negative correlation with the $\Delta PM_{2.5}$, revealed that economic development is environmentally sound while the mechanism remains to be analyzed. Additionally, a significant positive effect of EM on $\Delta PM_{2.5}$ was found during the winter, revealed the need of strict control on pollution emissions in winter.

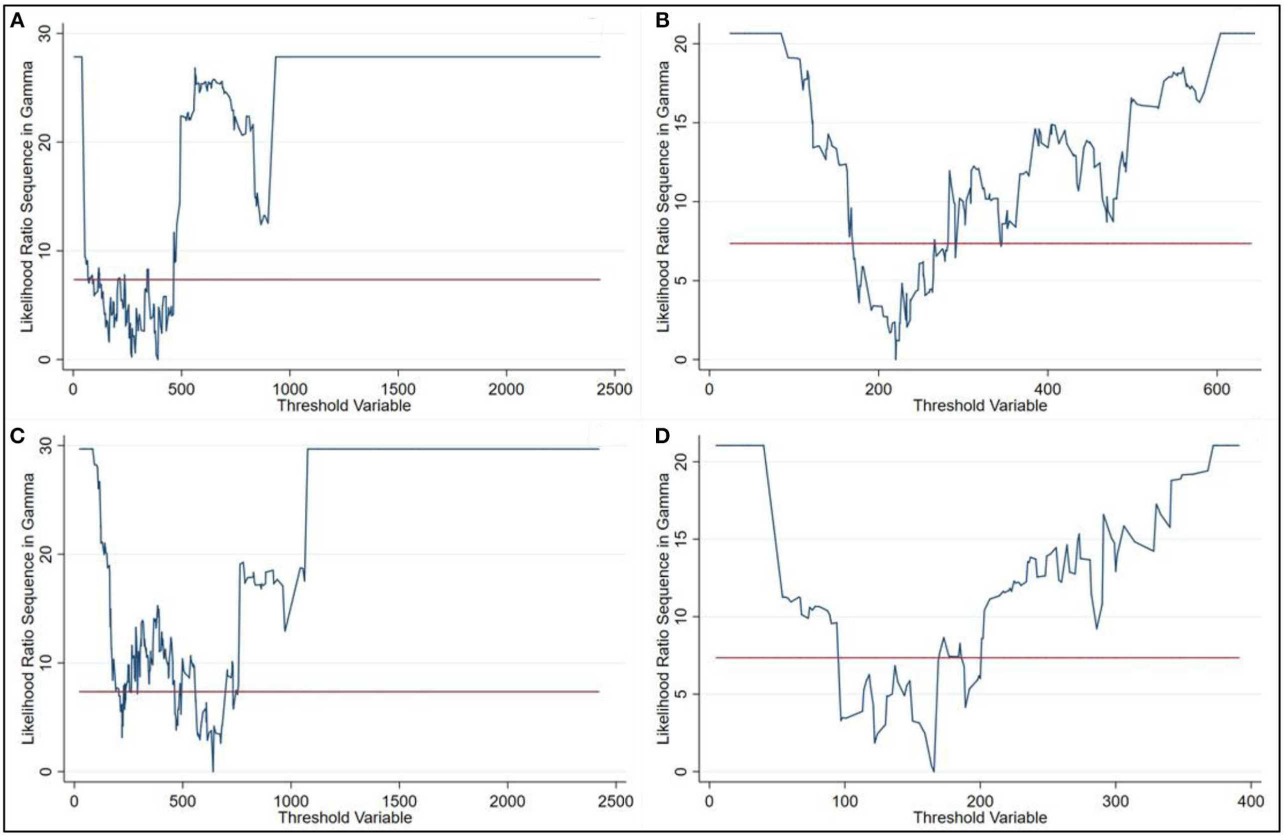

FIGURE 4 | Confidence interval construction in **(A,B)** Urban resident population threshold; **(C,D)** Population density threshold.

Pointwise Marginal Coefficients

The KRLS model was adopted in this study to examine the changes in marginal effects of GC with variation of other variables. This study focused not only on the effects of predictors on haze pollution but also on its heterogenicity varied with latitude and season. In addition, we have also introduced urban maintenance expenditure as control variable, focusing on urban development patterns hidden behind these variables and corresponding mitigation measures.

To evaluate statistically significant interaction effects, additional analyses were conducted by regressing pointwise derivatives of a given independent variable on other predictors, one at a time (49).

Figure 6A explored the distribution of the pointwise marginal effects of GC, the negative impacts of GC tend to increase as GC increase while cities with high government environmental investment (above 5% of GDP) having stronger negative driving effect under the same green cover level. This means that government financial support can benefit urban greening. There are no significant North-South differences observed in GC in the **Figure 6B**. The pointwise marginal effect of GC in summer/winter has been shown in **Figures 6C,D** considering the large difference of the surface landscape in the north and south regions. It can also be easily inferred from the figures that GC has a constant negative coefficient at all stages in southern citise (latitude $< 32°$N), but there's a change of sign from positive to negative for that in northern cities. This heterogeneity suggests that other factors interfere with the deposition of particulate matter by vegetation cover. **Figures 7A,B** further ascertain the spatial distribution of marginal effect of GC, finding that marginal effect of GC, especially during leaf-less period, had high values in areas where the background value of $PM_{2.5}$ was relatively high. Therefore, how the influence of background $PM_{2.5}$ concentration on GC coefficient varies with NS is shown in **Figures 6E,F**. The increase in the concentration of $PM_{2.5}$ has no significant effect on the coefficient of GC in the southern cities (latitude $< 32°$N), where levels of pollutants are relatively low. However, for cities located in the north with relatively high background $PM_{2.5}$ concentrations, the increase of GC will lead to the increase of haze concentration, which is especially obvious in winter. But the conclusion is not universal, as is shown in **Figures 6G,H**, for cities with high government environmental support, the increase of green cover can still effectively reduce haze pollution in high pollution scenarios.

Figure 8 discussed how other urban elements (population density and economic strength affect their coefficient estimates on $\Delta PM_{2.5}$. It can be easily inferred from the **Figure 8A** that per unit growth of population density could effectively restrain

TABLE 4 | Threshold regression model estimation.

	Dependent variable: $\Delta PM_{2.5}$					
Threshold	**I**	**II**	**III**	**IV**	**V**	**VI**
	Pop <= 220.18	**220.18 < Pop <= 640.22**	**Pop > 640.22**	**Den <= 165.78**	**165.78 <Den <=391**	**Den > 391**
GC	−0.344**	−0.118	−0.220	−0.095	−0.443**	0.125
HU	−0.563	−1.491*	−1.441	−1.567**	−1.987	−0.571
PD	0.067	−0.142	0.014	0.406**	0.048	0.105
IE	0.097	0.053	0.395*	−0.104	0.029	0.172*
PG	0.029	−0.351*	−0.139	−0.056	0.057	−0.666**
N/S	0.434	0.354	0.501	0.069	0.591	0.402
R^2	0.326	0.345	0.308	0.244	0.397	0.217
Obs	60	172	53	68	94	123
Dependent variable: $\Delta PM_{2.5}$(winter)						
GC	−0.445***	−0.126	−0.148	−0.132	−0.299*	0.048
HU	−1.173*	−0.122	0.863	−1.484**	−2.223	−0.280
PD	0.119	−1.488*	−0.136	0.212	0.232	0.100
IE	0.096	0.168**	0.455*	0.020	0.060	0.245*
PG	−0.047	−0.240	0.127	−0.166	−0.009	−0.350
N/S	0.617*	0.724***	1.453*	0.383	0.733*	0.961**
R^2	0.552	0.438	0.292	0.361	0.502	0.254
Obs	60	172	53	68	94	123

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

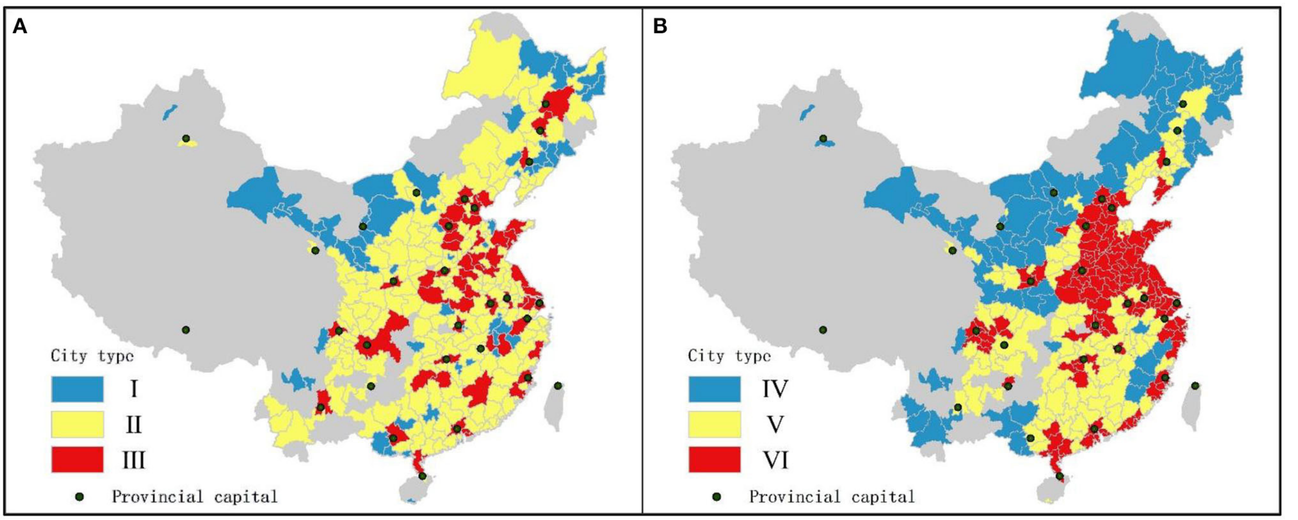

FIGURE 5 | Concentration spatial patterns of cities samples by: **(A)** Urban resident population threshold; **(B)** Population density threshold.

haze pollution in cities with high government environmental expenditure, while in those with low government environmental expenditure, the marginal effects of GC change from negative to positive as population density increases. From the pattern exhibited in **Figure 8B**, GC appears to function through two pathways in different stages of economic development due to different urban maintenance expenditure (UE). In cities with low UE, Increasing in PG usually leads to higher air pollution during the early stage of economic development. When the economy and income levels reach a certain threshold, the further increase in revenue will improve the environmental quality or reduce the pollution level. In cities with high UE, the marginal effect of GC becoming more noticeable with advancing PG.

The marginal effect of PG and PD were also shown in **Figure 8**. **Figure 8C** shows that PG yielded no main effect on dependent variables at high UE; further focus on cities with low

TABLE 5 | Results with the OLS and KRLS models.

	OLS	KRLS				
	Coef.	Avg.	SE	P25	P50	P75
Variables: $\Delta PM_{2.5}$						
GC	−0.14	−0.129*	0.065	−0.262	−0.163	−0.023
HU	−1.065*	−1.190**	0.367	−1.910	−1.246	−0.510
PD	−0.164**	−0.195***	0.051	−0.348	−0.217	−0.056
IE	0.0868	0.054	0.038	−0.028	0.049	0.139
PG	−0.307*	−0.224*	0.091	−0.339	−0.184	−0.051
*N/S	0.366***	0.327*	0.135	0.145	0.285	0.453
R^2	0.306	0.442				
Variables: $\Delta PM_{2.5}$(summer)						
GC	−0.208*	−0.157**	0.051	−0.265	−0.151	−0.066
HU	−0.955	−0.686**	0.207	−0.989	−0.732	−0.393
PD	0.128	0.007	0.042	−0.077	0.001	0.091
IE	0.0926	0.045	0.032	0.001	0.051	0.083
PG	−0.111	−0.059	0.071	−0.186	−0.057	0.058
*N/S	0.530**	0.412***	0.102	0.266	0.442	0.577
R^2	0.204	0.274				
Variables: $\Delta PM_{2.5}$(winter)						
GC	−0.139	−0.092	0.070	−0.185	−0.110	0.027
HU	−1.035	−1.236**	0.358	−1.895	−1.423	−0.593
PD	−0.179*	−0.188**	0.056	−0.310	−0.210	−0.080
IE	0.159**	0.111**	0.042	0.042	0.104	0.173
PG	−0.223	−0.178	0.099	−0.344	−0.157	−0.023
*N/S	0.740***	0.550***	0.142	0.415	0.566	0.697
R^2	0.365	0.443				

*Coefficient estimates at the 1st, 2nd, and 3rd quartiles are displayed in **Table 5** to show their distribution, and the first column of the KRLS model data indicates the average pointwise marginal effect. *$p < 0.05$, **$p < 0.01$, ***$p < 0.001$.*

UE, as is shown in **Figure 8D**, PD had no significant effect on $\Delta PM_{2.5}$ in northern cities but can effectively improve urban haze pollution in southern, with that effect in developed cities more remarkable. Finally, the bottom graphs **Figures 8E,F** shows there was heterogeneity of marginal effect of PD differed by season and North-South position. In summer (**Figure 8E**), increases in PD could decrease $\Delta PM_{2.5}$ in southern cities but increased haze pollution in northern cities, the effect fades following the addition of population density such that the marginal effect of PD approached 0 in big cities. In winter (**Figure 8F**), if exceeded a certain threshold, population density will help mitigate haze pollution.

DISCUSSION

A significant correlation between GC and $PM_{2.5}$ has been confirmed, based on the above empirical analysis. However, the marginal effect of GC is intricately affected by numerous urban elements, therefore, we use KRLS model to calculate marginal effects of changes in GC at the univariate level.

Urban maintenance expenditure is a new indicator of the importance to environmental protection; it is well-suited to examining $\Delta PM_{2.5}$ as an outcome variable since urban maintenance expenditure was observed in this study that has distinguished different urban development patterns, where obvious heterogeneity exists in the impact of greening coverage and other economic variables on haze pollution. Empirical results found that the increase of urban population density and economic intensity will not lead to the decrease of greening effect at the high-level UE phase, where marginal effect from greening is stronger than those with equal GC but low-level UE. In some cities where urban maintenance is relatively neglected, the increase of urban density will lead to the decrease of greening benefit and even the change of coefficient symbol. A similar interaction effects was also found between PG and benefit from GC (**Figure 8B**), with an increase in PG, the marginal effect of GC displayed a tendency of increasing first and then decreasing at low-level UE. These analyses revealed that urban maintenance expenditure has important implications for air pollution prevention. In China, the state has strict standards for urban green coverage, local government prefers to plant street trees to meet the assessment criteria for its low maintenance costs and no use of construction land. However, "Stresses the construction over the maintenance" may weaken the environmental benefits of urban greening; A large number of street trees to replace the park and grassland landscape will also lead to urban buildings too dense, particulate matter from human activity cannot be dredged. Regrettably, this study has therefore not included urban green space structure as indicators, but we can still find some suggestive support in recent studies. Nowak (5) and Chen (9) declared that vegetation is only a temporary retention site for many atmospheric particles and has its limit in the deposition capability, the leaves will eventually reach the saturation stage and cease to absorb more, as the ambient $PM_{2.5}$ concentration continues to increase (9), such that lead to an increase in $PM_{2.5}$ concentration (12). As a matter of fact, in some areas of the present study (especially in southern cities), it was observed that GC enhanced haze pollution at high-level background $PM_{2.5}$ concentration. Consequently, more consideration should be given to the role of urban greening maintenance and construction (urban forests and parks) in reducing haze pollution.

It was also found that the impacts of PD and GC on $\Delta PM_{2.5}$ were different between northern and southern cities, which was very rarely discussed before (14). The purpose of introducing dummy variables N/S was to quantify the unquantifiable variables, as the result demonstrated that such spatial heterogeneity indeed exists. At the same GC level, the mitigation of $PM_{2.5}$ by GC in southern cities was better than that in northern cities. For northern cities, PD had a positive effect on haze growth while significant negative effect may ensue (especially in winter) after reaching the threshold. For northern cities located on the plains with high population density and haze severe pollution, $PM_{2.5}$ concentrations are more dominated by pollution sources (traffic, heating) (38) since extreme growth of $PM_{2.5}$ during peak period could Restrict the settlement of greening as mentioned earlier. For southern cities, increasing population density tends to improve air quality, but in individual cities with particularly high population densities,

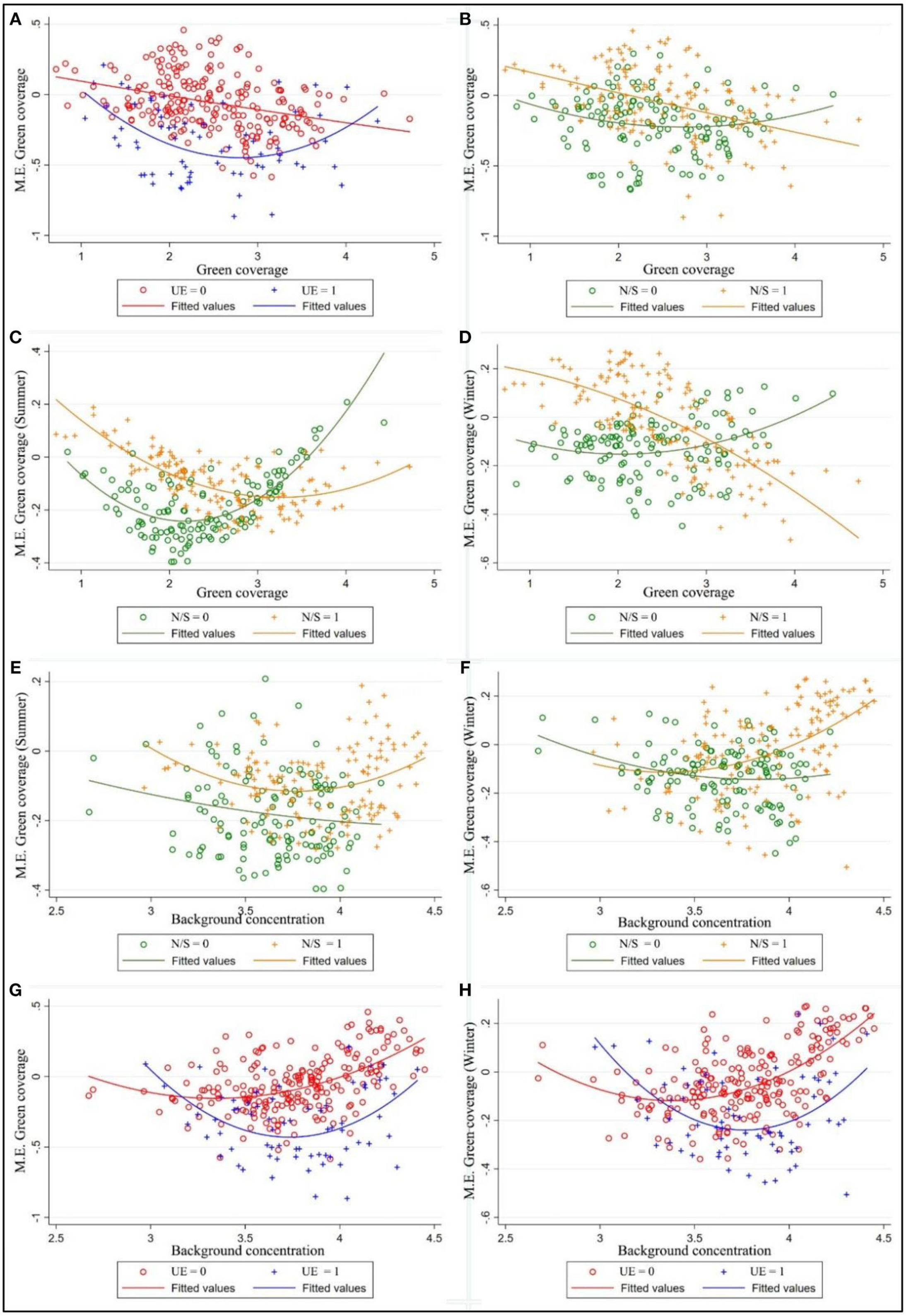

FIGURE 6 | Marginal effects (M.E.) of green coverage varying with values of green coverage **(A–D)** and background $PM_{2.5}$ concentration **(E–H)**. Note: The different figure panels represent the heterogeneous marginal effects of GR due to difference in season, dimension, and government environmental expenditure; UE = 1/0 means the ratio of urban maintenance expenditure to GDP greater/less than 5%; N/S = 1/0 means latitude of the city over/below 32°latitude limit.

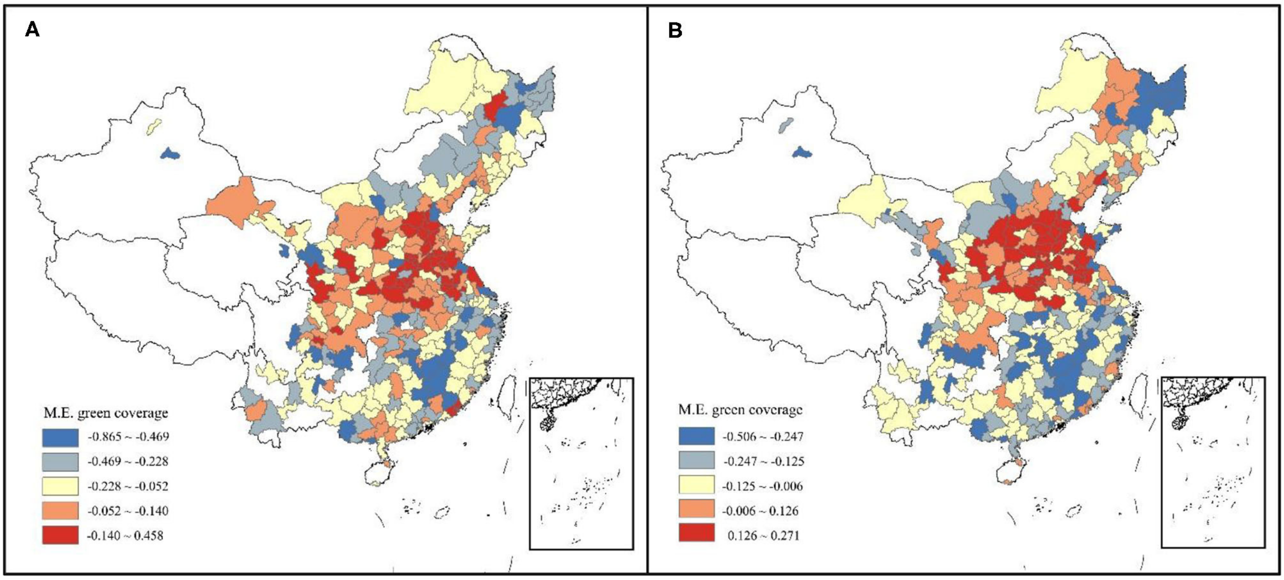

FIGURE 7 | Spatial patterns of marginal effect of green coverage per capita (GC) on: **(A)** Incremental $PM_{2.5}$ concentration; **(B)** Incremental $PM_{2.5}$ concentration in winter.

it also increases haze pollution. One study of 350 cities in the rapidly urbanizing Yangtze River Delta region of China reveals the phenomenon very well: The change in air quality as cities become more spatially sprawled or compact is largely a result of the trade-offs between two counterbalancing effects. On one hand, more geometrically compact and contiguous cities may have reduced vehicle travel distances and toxic air emissions. On the other hand, more spatially sprawled and fragmented cities may have increased intermixing of urban and forest land, and thus may facilitate removal of air pollutant (7). In addition, an extreme situation was also revealed in present study, for northern cities with less GR but higher background $PM_{2.5}$ concentrations, increased GR may exacerbate air pollution during peak hours due to low-level GR having positive effect on $\Delta PM_{2.5}$, therefore a vicious circle formed, reflecting the difficulty of haze management in such kind of cities.

The non-linear effect of economic growth on $PM_{2.5}$ emissions has been discussed in numerous studies (14, 16, 19), the conclusion is consistent with the Environmental Kuznets Curve theory. However, this interpretation is more suitable for air pollution from industrial emissions (factory production, urban construction, energy consumption) as government is willing to dramatically increase their budgets under public pressure (16). Our results in this study indicate that urban maintenance expenditure does not depend on levels of economic development, but still performed as well or better than benefit from economic development in mitigation of haze pollution, at least in peak period. On the one hand, the increment of particulate matter during this period may mainly come from the mobile source emissions rather than the industrial emissions [to reduce the harm of industrial emissions to residents, high-pollution enterprises are often located far away from densely populated built areas; due to cheap night electricity prices and pressure from government regulation, most industrial production activities are carried out at night (50)]. On the other hand, commuting, as a rigid demand of urban residents, is less affected by policies. A recent study by Zhang (51) has claimed that the policy measures from industrial sector and residential sector were the major effective control measures, together accounting for 92% of the national abatements in annual $PM_{2.5}$ concentrations, while another measure, strengthening vehicle emission standards, only contribute 2% of that. Therefore, the effectiveness of environmental regulation policies on the increment of particulate matter may seem limited during peak hours.

Based on the refined monitoring data, this study screened out the concentration changes of $PM_{2.5}$ in specific time periods to eliminate the interference of background concentration and spatial spillover effect, ensuring that the samples are comparable. Validation of this practice has been performed in other studies (11, 13, 38). We believe that the use of $PM_{2.5}$ increment instead of original concentration has the following advantages: Firstly, to our knowledge, no cross-sectional study has yet investigated the main emission sources of $PM_{2.5}$ at different times of the day, the present study was designed to begin filling the gap; Secondly, compared with the original concentration, the sudden increase of particulate matter concentration during the peak hours is obviously more related to human activities, mainly commuting traffic, more likely to take feasible measures for improvement. Thirdly, as for peak hours, the higher the concentration and the longer the duration, the greater the harm of haze to health, targeted research can provide positive and effective empirical evidence for decision makers to take measures to reduce the peak value of $PM_{2.5}$ concentration. In addition, since this study

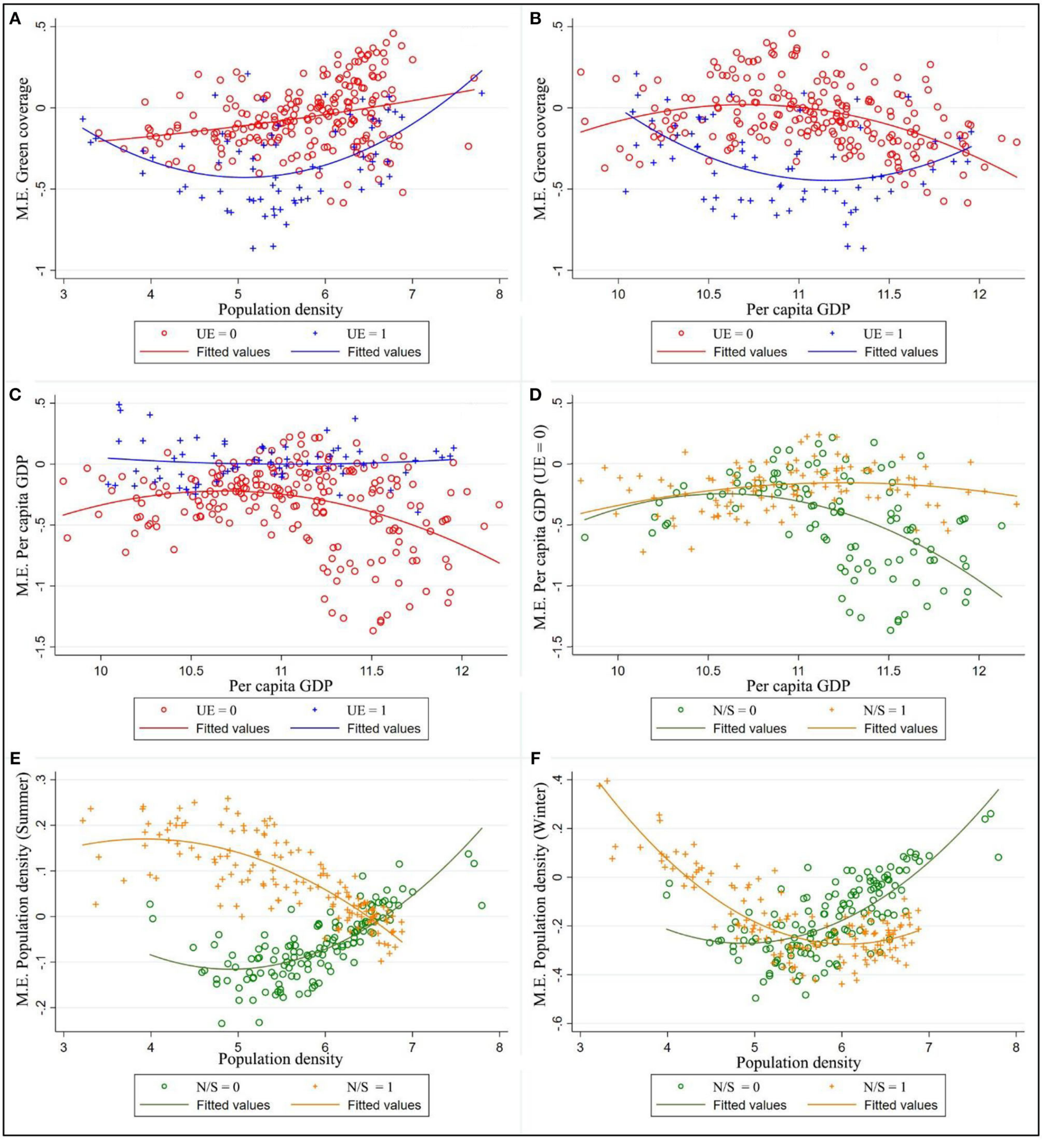

FIGURE 8 | Marginal effects (M.E.) of green coverage **(A,B)**, real GDP per capita **(C,D)** and population density **(E,F)** varying with values of urban elements. The different figure panels represent the heterogeneous marginal effects of GR, PG, PD due to difference in season, dimension, and government environmental expenditure; UE = 1/0 means the ratio of urban maintenance expenditure to GDP greater/less than 5%; N/S = 1/0 means latitude of the city over/below 32°latitude limit.

used a single-year cross-sectional data, the increment during peak hours, rather than original $PM_{2.5}$ concentration, is instead essential for lowering fixed effects to enable the comparability of data between cities.

As for social science modeling and inference problems, traditional piecewise linear regression usually use indicator variables with regression and classification problems, still relying on linearity or additivity assumptions, this requires that the marginal effect of each covariate is constant in the covariate space. However, this continued marginal effect assumption may be unreliable due to marginal effects being often heterogeneous in levels of other covariates. KRLS draws on machine learning methods designed to solve regression and classification problems without relying on linear or additive assumptions, allows users to tackle regression and classification problems without strong functional form assumptions or a specification search while also permitting more complex interpretation to examine non-linearities, interactions, and heterogeneous effects (27, 49, 50).

As pointed out by reviewers, the present study includes several limitations. First, due to complex interactions between human activities and the atmospheric environment, quantifying the influence of individual factors on $PM_{2.5}$ concentration remains challenging. On the one hand, a few overlooked sources of pollution do exist [e.g., cooking (33, 52), transportation (38), meteorological factors] in this paper. On the other hand, admittedly, emission reduction policy is an important factor affecting $PM_{2.5}$ concentration, since 285 cities involved in this study, it is difficult to quantify policy variables for horizontal comparisons between cities. Factors mentioned above should be included to improve model performance.

Second, the deposition effect of urban green on air quality might be too small to be detected in a single-year cross-sectional regression analysis, as the results of this study confirmed that other factors such as real GDP per capita, urban density, and air humidity have a more significant effect on $\Delta PM_{2.5}$ increment. Panel data models can obtain more efficient estimates than cross-sectional data and also reduce the impact of the omitted variable bias because panel data models use more information. It is regrettable that the data used in this paper comes from the China National Environmental Monitoring Center, which has released real-time air quality data since 2015, there will be the issue of independent variable skewness distribution if using a short-term annual data (green coverage in many cities remains unchanged in the short term).

At present, to our knowledge, no cross-sectional study has yet investigated the changes in the daily rhythm of main emission sources of $PM_{2.5}$ in the urban areas, we decided to point to this observation in the discussion, as this provides an interesting starting point for future research. In addition, background $PM_{2.5}$ concentration was an important factor affecting the marginal benefit of greening, it's a pity we have not explored this process specifically, which may inform design of future research studies that further explore these relationships (53).

CONCLUSIONS AND POLICY IMPLICATIONS

This study investigated the influence of urban greening and other urban elements on incremental concentration of $PM_{2.5}$ during peak hours. Firstly, the temporal (seasonal, diurnal) and spatial variation of incremental $PM_{2.5}$ concentrations in 285 cities in China has been explored. We use the threshold model to make an exploratory analysis on the influence factors of incremental $PM_{2.5}$ concentrations during peak hours ($\Delta PM_{2.5}$). For comprehensive results, a KRLS model was used to further explore the non-linearity, interaction, and heterogeneity among parameters. The main findings were as follows:

In addition to green coverage, the estimation results suggest that population density, real GDP per capita, government environmental investment are essential driving factors affecting $\Delta PM_{2.5}$. Additionally, the elasticity and significance of each independent variable to the dependent variable may vary across other independent variables level and will also change with season and latitude. To this end, we divide Chinese cities into three categories and adopt different measures to different regions according to local conditions and specific drivers. The results and implications are presented below.

Class I: Southern cities with low government environmental investment. In this kind of city, green cover and economic growth show strong effect on mitigating haze pollution at their respective high level. It was found that excessive population agglomeration can also exacerbate haze pollution. The green coverage per capita needs to be further improved for better air quality. On the one hand, the government should increase the expenditure of greening and air sector, on the other hand, for the densest urban areas, government should reduce the density of economic activities to allocate green resources rationally.

Class II: Northern cities with low government environmental investment. In this kind of city, population density and green coverage per capita were the main influencing factors of haze during the peak period. For cities in the central plains of China, with high background $PM_{2.5}$ concentration, haze pollution was enhanced by green coverage. Contribution of urban density to $PM_{2.5}$ concentration shows positive and negative effects at low and high levels, respectively. That's to say, more intensive development may have reduced vehicle travel distances and toxic air emissions in big cities. Therefore, the control and supervision of pollution sources is crucial for controlling haze pollution. At the early stages of urban development, mitigation interventions related to urban patterns have the greatest potential, reasonable urban planning should be made to reduce environmental stress for follow-up human activity intensive areas (traffic, green Infrastructure, urban Airway). For cities with high population density and smog pollution, a plausible spatial pattern is needed to reduce the burden of commuting, avoiding excessive population concentration, while offsetting the negative environmental impact of economic activities by improving the efficiency of land resource utilization and establishing more stringent policies to limit the discharge of pollutants from production and life.

Class III: Cities with high government environmental investment. Compared with other categories, it's a healthy urban development model that the increase of GC always effectively reduces haze concentration during peak period. In addition, the increase in population density and economic level also expanded the marginal effect of green coverage to reduce air pollution. Altogether, government environmental expenditure was observed to be a powerful means to reduce haze pollution during peak period in every stage of urban development and every region.

DATA AVAILABILITY STATEMENT

Publicly available datasets were analyzed in this study. This data can be found here: http://data.cnki.net

http://www.gtarsc.com/

http://www.cnemc.cn/sssj/

https://www.ceicdata.com/zh-hans

ftp://ftp.ncdc.noaa.gov/pub/data/noaa/isd-lite/.

AUTHOR CONTRIBUTIONS

SW: designed the manuscript, structured and wrote the manuscript, data processed and map designed, indicator calculation, and result analysis. SC: methodology for KRLS model. XQ: funding acquisition, validation, conceptualization, and supervision. All authors contributed to the article and approved the submitted version.

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SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2020.551300/full#supplementary-material

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Deciphering the Link Between Mental Health and Green Space in Shenzhen, China: The Mediating Impact of Residents' Satisfaction

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Rapid urbanization and increasing urban density in China threaten residents' mental health. As a vital component of built environments, green space plays a key role in individuals' psychological well-being; however, the mediating effect of residents' satisfaction with the green space environment on the relationship between urban greening and residents' mental health in Chinese contexts has yet to be thoroughly explored. To fill this knowledge gap, this paper attempts to reveal the internal logic and mechanism underlying the linkages between green space, residents' mental health, and their satisfaction with green space in Shenzhen, China. Specifically, this paper explores the mediating role of residents' satisfaction with a green space environment using questionnaire survey data, "Quick Bird-2" high-resolution remote sensing image data, and a multilevel regression model. Our empirical findings indicate that the relative range of neighboring green spaces can directly improve residents' mental health. More importantly, the relationship between the relative scope of green space and residents' mental health is mediated by residents' satisfaction with the green space environment rather than its direct health effects. Given the influence of green space on residents' satisfaction with the environment, green space indirectly affects mental health. These findings should provide the government useful guidance for considering the spatial distribution and quantity of green space. Our results should also help residents improve their actual experiences and subjective satisfaction with the green space environment.

Keywords: green space, mental health, satisfaction with green-space environment, multilevel regression model, Shenzhen

INTRODUCTION

Rapid urbanization has enlarged China's urban population dramatically; meanwhile, the quality of citizens' living environment has declined (1). Environmental protection is an urgent issue and a fundamental requirement for sustainable development. The construction of ecological civilization has been incorporated into China's national master plan, elevating ecological construction to the national strategic level. As people's living standards have improved, the importance of green space for mental health, especially for stress relief, has attracted the attention of the Chinese public (2, 3). As an aspect of urban construction, greening is responsible for a city's ecological functioning and has been shown to exert significant positive effects on Chinese residents' mental health (4) and well-being (1).

Urban green space, which is typically defined as vegetated open areas such as parks, gardens, playgrounds, and forests (5), has been considered increasingly essential to residents' mental health (6, 7). Over the past decade, research on the relationship between green space and mental health has shifted from qualitative to quantitative designs (8) due to dramatic breakthroughs in quantifying non-physical health benefits (9). Many studies have focused on the pathways through which green space affects mental health. Potential pathways are associated with two primary domains, namely restoring capacities and building capacities (7). For example, green space has been found to relieve residents' stress (10–14), depression (12, 14, 15) and psychological fatigue (10, 11), foster social cohesion (4, 12, 14, 16–18), improve residents' satisfaction (4), build mindfulness and resilience to stress (19), and promote residents' sense of security and adaptability (20). Prolonged exposure to a high-quality natural environment may inspire people to ponder their priorities and goals as well; doing so can help individuals identify new directions in life, which benefits mental health (21). In a recent study, Liu et al. found that stress and neighborhood social cohesion altogether had a complete mediation effect on the association between green exposure and mental health in China (12). Overall, associations between green space and various psychological and emotional benefits have been reported in studies with diverse samples (22–25).

Despite encouraging findings, the mental health benefits of green space for specific population groups or neighborhood settings appear inconsistent. Some researchers have reported correlations that defied their expectations. For example, no relationship has been observed between local green space availability and people's mental health: the presence of more green space was found to be associated with better mental health for men at any age but only for older women (26). No correlation manifested in the Netherlands between neighborhood green space and mental health among housewives or the elderly (27). Other studies have even uncovered adverse effects of green space on residents' mental health: a summary from the World Health Organization (2016) suggested that greater green space may be tied to potential or actual criminal activity (8). The possibility of crime can evoke fear, particularly among vulnerable groups such as women, children, and the elderly (9, 28). In addition, urban greening may raise property rents and taxes in neighboring areas, which could lead to the displacement of individuals with a lower socioeconomic status and evoke hidden risks of mental illness (29).

To date, studies have focused on the impact of residents' satisfaction with green space on their mental health. For example, past work showed that individuals' mental health improved when they were satisfied with green space (30, 31). Liu et al. identified a mediating effect of satisfaction when they investigated the pathways of possible mediators between green space and residents' mental health (4). These studies highlight the need to consider subjective measures of green space quality that may contribute to people's health status. Studies have likewise indicated that green space significantly contributes to neighborhood satisfaction and mental well-being (32). By contrast, Ruijsbroek et al. discovered a weak correlation between individuals' satisfaction with neighborhood green space and mental health (33). Another cross-sectional analysis revealed that green space was related to satisfaction and mental health; however, the specific association was not clear (34). This ambiguity may be due to the lack of a uniform definition of green space and its quality when elucidating green space satisfaction (35). The preceding review indicates that scant studies have explored the correlation between satisfaction derived from the quality of green space and individuals' health outcomes.

The topic of green space and mental health lends itself to case studies. Accordingly, relevant work has involved American, British, and other European cities (e.g., in Denmark); Australia; and the Chinese cities of Beijing and Guangzhou (4, 6, 9, 36). Many other parts of the world (e.g., most of Asia, Africa, less affluent European countries, and South America) have not been the subjects of such research. In light of the diverse ethnic and socioeconomic attributes of such populations, which were identified as confounds in Ruijsbroek et al.'s study (6), findings from focal areas may not necessarily apply elsewhere. These discrepancies cast doubt upon whether residents' emotions will benefit mental health similarly in developing countries compared with Western contexts. For example, most green space is owned and controlled by local governments in China. Given the unique associations between the government, green space, and residents, more specific and process-oriented research is needed to enrich our understanding of the complexities underlying associations between residents' satisfaction with green space and mental health (36).

In summary, evidence pertaining to the relationship between green space and residents' satisfaction and mental health remains thin (36–39). Satisfaction partially reflects the extent to which neighborhood green space enhances residents' mental well-being (4, 14). Even so, the mediating effect of residents' satisfaction with the green space environment on the relationship between urban greening and residents' mental health in Chinese contexts has yet to be thoroughly explored. The present study therefore delineates the relationship between residents' mental health and urban green space in Shenzhen, China, by examining the mediating effect of residents' satisfaction as recommended in prior studies (4, 9). The remainder of this paper is organized as follows: our data collection procedures and methodology are summarized in section Data and Methods; experimental results are described in section Results to reveal the mediating role of residents' satisfaction; and section Conclusion and Discussion presents our discussion and conclusion.

DATA AND METHODS

Data

Shenzhen, China was selected as the research area in this study. Shenzhen was a frontier city of China's reform and opening up and is an ideal setting in which to consider the mediating role of residents' satisfaction between green space and mental health. Following more than 30 years of rapid development, Shenzhen has grown into a modern city that stands at the forefront of large and medium-sized cities in China. According to Xinhuanet (40), in 2018, Shenzhen's per capita park and green area covered 16.0 m^2; its comprehensive air quality index was 3.15; and its environmental noise sound effect level was 57.5, ranking first in China's Green City Index. In August 2019, Shenzhen became the pilot demonstration zone for socialism with Chinese characteristics, continuing to promote green space construction. As of December 2019 (41), the green coverage rate in Shenzhen's built-up area was 43.40%, and more than 2,400 km of greenways spanned the city. However, to our best knowledge, the connection between Shenzhen residents' satisfaction with green space and their mental health remains uncertain and calls for deeper exploration.

Data for this study were derived from a questionnaire survey of Shenzhen residents in 2017. A total of 1,000 questionnaires were distributed, and 993 valid copies were returned (response rate: 99.3%). A mix of quantitative and qualitative methods was adopted. Survey respondents were recruited via a multi-stage, stratified proportionate probability sampling process. In the first stage, 10 residential neighborhoods (*shequ*) were randomly chosen from nine districts (i.e., Nanshan, Futian, Luohu, Yantian, Longgang, Baoan, Guangming, Longhua, and Pingshan), using stratified sampling in which the selection probability was proportional to the population size (**Figure 1**). In the second stage, we randomly selected 100 households from sampled neighborhoods (i.e., Hongling *shequ*, Songyuan *shequ*, Gangxia *shequ*, Dachong *shequ*, Fuhua *shequ*, Dexing *shequ*, Yongan *shequ*, Baihua *shequ*, Liyuan *shequ*, and Shijing *shequ*) and used a Kish grid to select the member to be interviewed from each household.

The survey solicited respondents' sociodemographic characteristics (i.e., age, gender, education, marital status, employment, Hukou status, and family income); see **Table 1**. Respondents were 40 years old on average, and 94.96% were married. The sample contained slightly more men (51.86%) than women (48.14%). Regarding education level, less than

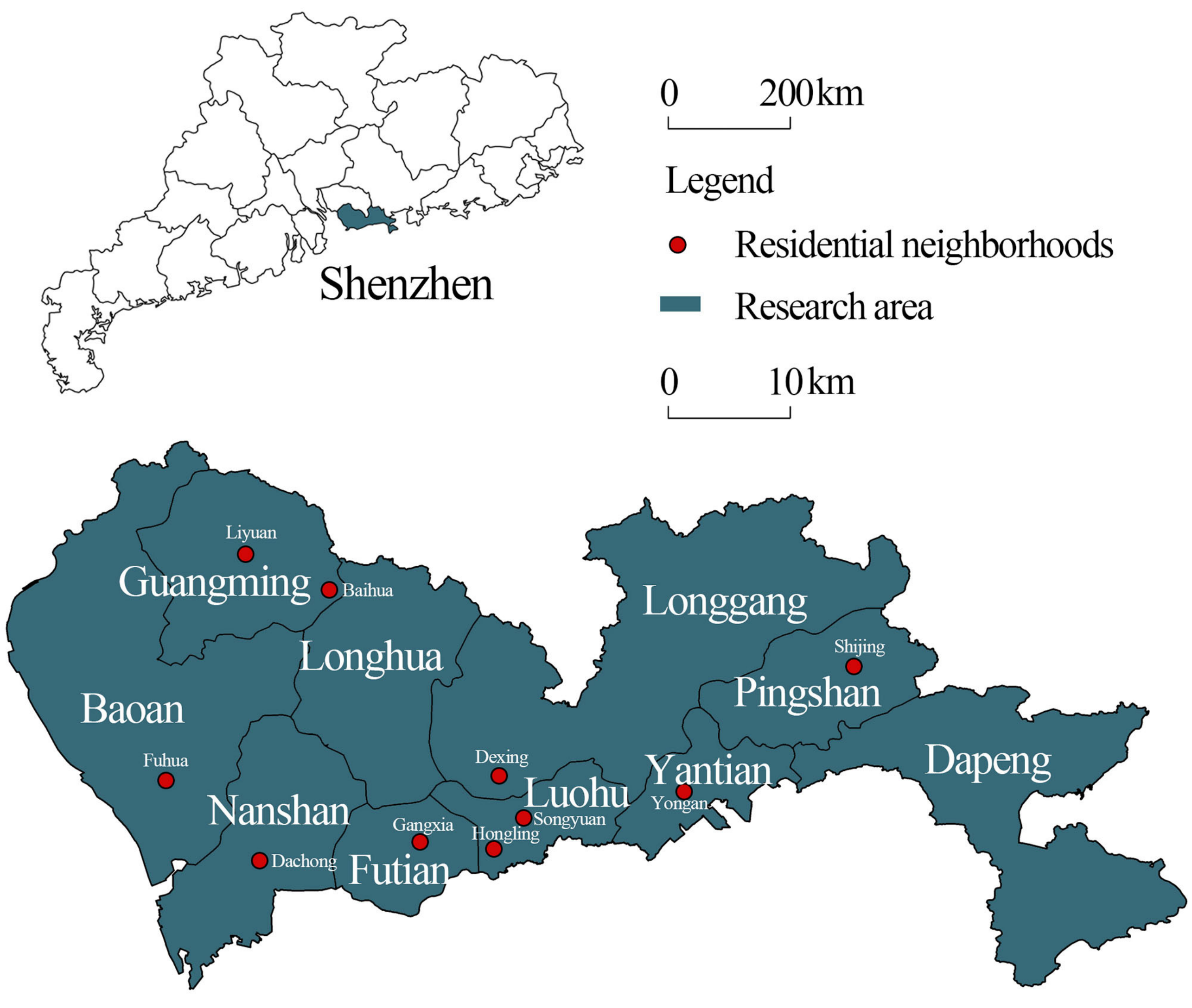

FIGURE 1 | Map of Shenzhen and the locations of the 10 selected neighborhoods.

TABLE 1 | Social demographic characteristics of population of this study and Shenzhen.

Variables	Proportion (%)/Mean (Standard deviation)	
	Population of this study	**Total population of Shenzhen (2010)**
Size	993	10,358,381
Age	40.11	29.89
Gender		
Male	51.86%	54.19%
Female	48.14%	45.81%
Education		
Primary school or below	28.50%	10.09%
High school	34.44%	71.38%
College/University/Above	37.06%	18.53%
Marital status		
Married	94.96%	59.55%
Single/Divorce/Widowed	5.04%	40.45%
Employment		
Employed	74.62%	73.21%
Unemployed/Retired	23.18%	-
Students	2.20%	-
Hukou status		
Shenzhen Hukou	43.50%	17.80%
No-Shenzhen Hukou	56.50%	82.20%
Family income (Yuan/Year)		
Below 25,000	4.87%	-
25,000–100,000	58.61%	-
100,000–200,000	21.65%	-
200,000 and above	12.74%	-
Refused	2.13%	-

one-third of respondents (28.50%) had a primary school education, 34.44% possessed a secondary school education, and 37.06% held an undergraduate degree or above. Most respondents were employed. More respondents held a household registration in Shenzhen than not. In terms of annual family income, 4.87% of respondents earned less than 25,000 CNY, most (58.61%) earned between 25,000 and 100,000 CNY, 21.65% earned 100,000–200,000 CNY, and 12.74% earned more than 200,000 CNY.

Framework

First, we adopted "Quick Bird-2" high-resolution remote sensing image data to accurately depict the spatial distribution of urban green space in Shenzhen; this program was used to calculate the ratio of green space in each target neighborhood. We employed ArcGIS software to establish a current interpretation map of Shenzhen's green space. Second, we used stratified sampling to survey 993 residents on their mental health and satisfaction with the local green space environment. We measured mental health using the 12-item General Health Questionnaire (GHQ-12) (42), whose items pertain to respondents' psychological feelings over the past week at the time of the survey. Third, we

TABLE 2 | Measured items of constructed dimensions.

Constructed dimensions	Variables name	Items
Satisfaction with green-space environment Standardized Cronbach's α = 0.823	RS01	Level of satisfactory with Recreation Facilities
	RS02	Level of satisfactory with Neighborhood Green infrastructure
	RS03	Level of satisfactory with Neighborhood living environment
Mental health Standardized Cronbach's α = 0.828	MH01	Able to Concentrate
	MH02	Loss of sleep over worry
	MH03	Playing a useful part
	MH04	Capable of making decisions
	MH05	Felt constantly under strain
	MH06	Couldn't overcome difficulties
	MH07	Able to enjoy day-to-day activities
	MH08	Able to face problems
	MH09	Feeling unhappy and depressed
	MH10	Losing confidence
	MH11	Thinking of self as worthless
	MH12	Feeling reasonably happy

considered the mediating role of residents' satisfaction in the local green space environment between residents' mental health and the environmental impact of urban green space. Finally, we developed multilevel linear models to explore the internal logic and mechanisms related to green space, residents' mental health, and residents' satisfaction with the green space environment.

Variables

Outcomes

Although the term "mental health" has no uniform definition, common measurement scales include the GHQ-12, Self-rating Depression Scale (43), Medical Outcomes Study and 36-item Short Form Survey (44). As noted, we applied the GHQ-12 in this study; this instrument is one of the most widely used methods to assess mental health (45–50). The scale's 12 items relate to respondents' psychological feelings over the past week at the time of the survey (see **Table 2**). Six items are scored on a 5-point Likert-type scale indicating frequency (1 = "at no time," 5 = "all of the time"); sample statements include "Loss of sleep over worry," "Capable of making decisions," and "Could not overcome difficulties." The remaining six items are reverse scored on the same 5-point Likert-type scale (1 = "all of the time," 5 = "at no time"; e.g., "Able to concentrate," "Playing a useful part").

Green Space

Scholars have generally used investigator observation records to record green space. However, such records can suffer from severe subjective bias. Therefore, we referred to "Quick bird-2" high-resolution remote sensing image data, with a spatial resolution of up to 0.5 m, to calculate the ratio of green space in each case neighborhood. According to the image characteristics of green

TABLE 3 | The mental health of Shenzhen residents.

Social-demographic	Variables	Mental health		
		SD	***T*-value**	***P*-value**
Gender	Male	1.957	−1.352	0.177
	Female	1.959		
Age	Before the 1985s	1.924	1.181	0.238
	After the 1985s	1.967		
Marital status	Married	1.943	−0.919	0.359
	Single/Divorce/widowed	2.025		
Education	No high education	1.908	−6.987	0.000
	College/university/above	1.922		
Hukou status	Shenzhen Hukou	1.940	−0.513	0.608
	Non-Shenzhen Hukou	1.974		
Political status	Party member	1.911	−5.574	0.000
	Non-Party member	1.932		
Entire sample		1.959		

space (e.g., color, texture, shape, location, and other properties), we determined the interpretation marks and then analyzed remote sensing images together with the actual circumstances in Shenzhen to obtain vector patch data for urban green space interpretation. We next used ArcGIS to construct a current interpretation map of the city's green space using graphics and corresponding data. We also developed an associated greening information database.

Mediators

Residents' satisfaction with Shenzhen's green space environment was based on three types of amenities (i.e., recreational facilities, green infrastructure, and living environment, please refer to **Table 2**). Satisfaction scores ranged from 1 ("very unsatisfactory") to 5 ("very satisfactory"). We then performed principal component analysis to extract components for all items and calculated respondents' satisfaction index.

Control Variables

Multiple individual- and neighborhood-level variables were taken as control variables. Individual-level covariates were as follows (see **Table 3** for details): respondent's age (in years), gender (male or female), educational attainment (e.g., primary school or below), Chinese Communist Party membership (yes or no), marital status (single/divorce/widowed vs. married), Hukou status, annual family income, residence length, housing tenure, and social contact size. The five neighborhood-level control variables in this study consisted of point-of-interest (POI) density, bus station density, population density, social trust, and neighborly interactions. Among them, POI density, bus station density, and population density constituted built environmental indicators, while social trust and neighborly interactions were social environmental indicators.

Data Analysis

We used multilevel linear modeling to unveil the internal logic and mechanisms among green space, residents' mental health, and their satisfaction with the green space environment. The general form of the multilevel regression model can be expressed as follows:

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

Where Y_{ij} is the mental health index of resident i of neighborhood j, X_{ij} represents individual-level variables of resident i of neighborhood j, and Z_j denotes neighborhood-level variables. α and β denote variation coefficients of individual-level variables and neighborhood-level variables, respectively. μ_j is the random effect of unobservable factors at the neighborhood level, ε_i represents the random effect of unobservable factors at the individual level, and β_0 is a constant.

Variant between-group differences (i.e., between neighborhoods) should be considered during model selection; a multilevel regression model should be adopted if groups exhibit large differences. Therefore, we introduced the dependent variable (i.e., no independent variable was entered) and calculated the intra-class correlation coefficient (ICC) as follows:

$$ICC = \frac{\sigma_b^2}{\sigma_w^2 + \sigma_b^2}$$

Where σ_b^2 represents the variance between neighborhoods, and σ_w^2 denotes individual variance within the neighborhood. A larger ICC value indicates that the inter-group variance is significantly greater than the intra-group variance, demonstrating that residents' mental health in the same neighborhood is correlated. In this case, a multilevel model is justified. On the contrary, if the inter-group variance is small and the ICC value is small or close to zero, single-level regression would be more appropriate. Between-group differences could not be ignored in our study; therefore, we chose a multilevel regression model.

RESULTS

Relationship Between Green Space and Mental Health

We conducted multilevel linear regression modeling to quantify the effects of individual attributes and the residential environment. Variance inflation factors (1.99) were lower than 3, and the ICC for the null model (0.122) suggested that the residential environment accounted for 12.2% of the variance in residents' mental health. **Table 4** summarizes the correlation between green space and mental health. Statistically significant and positive associations between the ratio of green space and residents' mental health implied that the higher the ratio, the better residents' mental health. This finding is consistent with our initial expectations and common sense. First, according to restoration theory, the inherent quality of green space can enhance health or well-being; simply viewing green space can elicit positive effects (51). Second, green space is associated with a healthier environment, including lower air pollution and noise (52, 53). Third, green space can promote mental health by providing an area for sports activities and social interaction, as indicated in prior studies (54, 55). Among neighborhood-level

TABLE 4 | The association between green space and mental health.

	Mental health			
	coef.	**S.E.**	***T*-value**	***P*-value**
Neighborhood-level variables				
Green space rate	0.226	0.114	(1.99)	0.047**
POI density	0.120	0.152	(0.79)	0.432
Bus station density	0.103	0.153	(0.69)	0.488
Population density	−0.060	0.108	(−0.56)	0.578
Social trust	0.208	0.067	(3.12)	0.002***
Neighborly interactions	0.065	0.196	(0.33)	0.740
Individual-level variables				
Age (reference group: <35 age cohort)				
35 ∼ 45 age cohort	−0.092	0.131	(−0.70)	0.482
>45 age cohort	−0.091	0.209	(−0.44)	0.662
Gender (reference group: male)	0.192	0.112	(1.71)	0.088*
Education (reference group: lower education)				
Higher education	0.388	0.202	(1.92)	0.055*
Middle education	0.086	0.140	(0.61)	0.539
Party membership (reference group: non-party membership)				
Party membership	0.544	0.195	(2.79)	0.005***
Marital status (reference group: married)				
Single/Divorce/Widowed	0.154	0.280	(0.55)	0.582
Hukou status (reference group: non-Shenzhen Hukou)				
Shenzhen Hukou	−0.056	0.145	(−0.39)	0.698
Income	1.223	0.469	(2.61)	0.009***
Residence length	−0.025	0.092	(−0.27)	0.787
Housing tenure (reference group: renter)				
Homeowner	0.618	0.212	(2.91)	0.004***
Social contact size	0.172	0.090	(1.92)	0.054*
Constant	−0.560	0.182	(−3.07)	0.002***
Observations		993		

**p < 0.1, **p < 0.05, ***p < 0.01.*

TABLE 5 | The association between green space and resident's satisfaction with green-space environment.

	Satisfaction with green-space environment			
	coef.	**S.E.**	***T*-value**	***P*-value**
Neighborhood-level variables				
Green space rate	0.438	0.152	(2.89)	0.004***
POI density	0.676	0.276	(2.45)	0.014**
Bus station density	−0.146	0.172	(−0.85)	0.396
Population density	−0.355	0.275	(−1.29)	0.198
Social trust	−0.093	0.134	(−0.69)	0.490
Neighborly interactions	−0.100	0.220	(−0.46)	0.649
Individual-level variables				
Age (reference group: <35 age cohort)				
35 ∼ 45 age cohort	−0.182	0.097	(−1.88)	0.060*
>45 age cohort	−0.010	0.140	(−0.07)	0.944
Gender (reference group: male)	0.018	0.117	(0.16)	0.877
Education (reference group: lower education)				
Higher education	0.139	0.148	(0.94)	0.350
Middle education	−0.001	0.090	(−0.01)	0.991
Party membership (reference group: non-party membership)				
Party membership	0.297	0.127	(2.35)	0.019**
Marital status (reference group: married)				
Single –person	−0.216	0.163	(−1.32)	0.186
Hukou status (reference group: non-Shenzhen Hukou)				
Shenzhen Hukou	−0.100	0.087	(−0.15)	0.252
Income	−0.052	0.135	(−0.39)	0.699
Residence length	−0.014	0.077	(−0.19)	0.581
Housing tenure (reference group: renter)				
Homeowner	−0.062	0.185	(−0.33)	0.739
Social contact size	0.035	0.047	(0.75)	0.455
Constant	0.206	0.163	(1.26)	0.207
Observations			993	

**p < 0.1, **p < 0.05, ***p < 0.01.*

covariates in this study, a negative correlation emerged between population density and mental health. Conversely, POI density, bus station density, social trust, and neighborly interactions each positively influenced mental health with social trust being most noteworthy: social trust can foster residents' mental health, although this correlation is difficult to verify through casual observation. In terms of individual-level variables, gender, higher education, party membership, income, home ownership, and social contact size all had significant positive effects on Shenzhen residents' mental health.

Relationship Between Green Space and Mediator

The relationship between green space and residents' satisfaction with the local green space environment is outlined in **Table 5**. Results revealed a significant positive association between these two dimensions. The independent variable (green space) had significant positive effects on predicting residents' satisfaction with the green space environment. Specifically, a 1-point increase in green space produced a 0.438-point increase in residents' satisfaction with the green space environment. This trend suggests that residents living in neighborhoods with relatively more green space are more likely to express greater satisfaction with the green space environment.

With respect to neighborhood-level covariates, POI density had a significant positive impact on residents' satisfaction with the green space environment. Such density reflects the abundance of community green space: the higher the POI density, the greater the community's green space. As mentioned, green space also offers residents an area for leisure and recreation, thus increasing satisfaction with the green space environment. By contrast, bus station density, population density, social trust, and neighborhood interaction adversely affected residents' satisfaction with the green space environment. This pattern may have manifested because some individuals prefer to enjoy green space without being disturbed by others. On an individual level, respondents between 35 and 45 years old demonstrated lower satisfaction with Shenzhen's green space environment, whereas party membership status was significantly positively correlated with residents' satisfaction. These demographic factors may affect people's use of green space, thus shaping their overall satisfaction

TABLE 6 | Mediation effect for residents' mental health.

	Mental health			
	coef.	**S.E.**	***T*-value**	***P*-value**
Neighborhood-level variables				
Green space rate	0.113	0.107	(1.06)	0.290
POI density	−0.028	0.176	(−0.16)	0.876
Bus station density	0.140	0.128	(1.09)	0.275
Population density	0.006	0.122	(0.05)	0.964
Social trust	0.226	0.065	(3.48)	0.000***
Neighborly interactions	0.084	0.157	(0.53)	0.594
Individual-level variables				
Age (reference group: <35 age cohort)				
35 ∼ 45 age cohort	−0.052	0.128	(−0.40)	0.687
>45 age cohort	−0.102	0.219	(−0.47)	0.641
Gender (reference group: male)	0.185	0.109	(1.69)	0.090*
Education (reference group: lower education)				
Higher education	0.339	0.223	(1.52)	0.129
Middle education	0.085	0.144	(0.59)	0.555
Party membership (reference group: non-party membership)				
Party membership	0.457	0.179	(2.55)	0.011**
Marital status (reference group: married)				
Single -person	0.212	0.296	(0.72)	0.474
Hukou status (reference group: non-Shenzhen Hukou)				
Shenzhen Hukou	−0.055	0.145	(−0.38)	0.705
Income	1.261	0.468	(2.69)	0.007***
Residence length	−0.007	0.084	(−0.08)	0.935
Housing tenure (reference group: renter)				
Homeowner	0.617	0.200	(3.08)	0.002***
Social contact size	0.167	0.079	(2.13)	0.033**
Mediator variable				
Residential satisfaction	0.260***	0.051	(5.09)	0.000***
Constant	−0.572	0.198	(−2.90)	0.004***
Observations		993		

**p* < 0.1, ***p* < 0.05, ****p* < 0.01.

with the green space environment, as demonstrated in past work (55).

Mediating Effect of Residents' Satisfaction With Green Space Environment

Residents' satisfaction with the green space environment was associated with their mental health scores, and the correlation between greenness and mental health became non-significant after adding residents' satisfaction into the regression model (see **Tables 6**, **7**). This finding suggests that the relationship between greenness and mental health may be mediated by residents' satisfaction. Compared with **Table 4**, the impact coefficient of the rate of green space on residents' mental health declined from 0.226 to 0.113. In other words, the mediator (i.e., residents' satisfaction with the green space environment) played a mediating role and indirectly suppressed the direct effect of the independent variable (i.e., ratio of green space) on the dependent variable (i.e., mental health). This trend suggests that residents' satisfaction is likely to influence the relationship between green space availability and mental health. Accordingly, green space indirectly affects mental health.

TABLE 7 | Goodness-of-fit of model.

	Entire sample
Sobel	0.008***
Proportion of total effect that is mediated	1.138
Ratio of indirect to direct effect	0.278

****p* < 0.01.

Among community-level covariates, social trust was found to have a major effect on mental health. On an individual level, respondents' gender, party membership, income, home ownership, and social contact scale each had significant positive impacts on mental health. Gender is known to influence health-related lifestyles and may be particularly important in green space access (56); notably, gender affects individuals' perceptions and use of the environment. The discrepant impacts of party membership on the environment and mental health may be due to differences in lifestyle and work habits or to the inclusion of groups in certain environments. Income positively affects individuals' mental health because vulnerable communities (e.g., where people earning low incomes reside) lack the economic resources and political power required for environmental risk control. This weak social support can exacerbate residents' fragile mental states; for example, poverty has been shown to be affected by individuals' mental health (57, 58). Additionally, greater social contact has been tied to a stronger sense of trust, belonging, and acceptance, which may promote mental health benefits (38).

CONCLUSION AND DISCUSSION

China's urban population has ballooned amid swift urbanization. As the percentage of people living in urban environments continues to rise, increasingly dense urban areas have begun to threaten residents' mental health. A better understanding of the various potential benefits of urban green space on residents' mental health is urgently needed and warrants careful consideration. The present study was inspired by a paucity of robust evidence vis-à-vis the link between mental health, residents' satisfaction, and green space. We explored the robustness of these associations and how green space is associated with mental health. Specifically, this study aimed to investigate whether Shenzhen residents' satisfaction with the local green space environment mediated the association between green space and mental health. Questionnaire survey data were gathered from 993 Shenzhen residents in 2017, and "Quick Bird-2" high-resolution remote sensing image data were adopted to calculate the ratio of green space in each case neighborhood and build a green space map of the area. A corresponding information database was then established in ArcGIS. Finally, residents' mental health was evaluated based on the GHQ-12. The novelty of this study is 2-fold. First, we assessed the mediation effect of residents' satisfaction with the green space environment on the relationship between urban greening and mental health in a frontier city in China. Second, we referred to multiple data sources and multi-level data structures to draw conclusions; that is, we considered questionnaire data along with remote sensing data that had a higher spatial resolution compared to the Normalized Difference Vegetation Index used in Liu et al.'s study (4). This multi-level data enabled us to investigate community attributes as well as individual (resident) attributes.

This study offers several valuable insights. First, previous research indicated mixed results regarding the correlation between natural environments and self-rated health (36). Besides Liu et al. (4), our findings provide additional empirical support for the potential mediating role of residents' satisfaction in the relationship between green space and mental health, unveiling that a neighborhood's relative extent of green space can directly improve residents' mental health. These patterns also align with earlier work indicating that neighborhood green space can reduce the risk of mental illness and thus enhance mental health (59–62). Second, our results imply that, different from physical health, individuals' mental health is more implicitly affected by their surrounding environment. The internal mechanism of this influence is complicated, and more research is needed to test and clarify possible mediators (63). Third, the present study bridges a knowledge gap in research on the association between the relative extent of green space, residents' mental health, and potential mediating mechanisms between them in a Chinese city other than Beijing (36) or Guangzhou (4). Because data related to green space and health were derived from different sources in this study, our sample was less susceptible to single-source bias. We also used objective measures of green space based on remote sensing data to promote the reliability of our findings. New technological tools such as "Quick Bird-2" high-resolution data, together with responses to the GHQ-12, produced diverse information to offer an objective, standardized approach for validation studies, as mentioned in prior research (51). Fourth, our results highlight the importance of considering subjective assessments of green space quality (e.g., from residents' points of view) with respect to health benefits. These findings offer potential guidance for stakeholders in pondering environmental justice relative to the provision of green space. Fifth, the relationship between green space, mental health, and residents' perceived satisfaction may vary across cultures or regions. Our mediation analyses showed that, against the backdrop of China's rapid urbanization (e.g., in Shenzhen), residents' satisfaction with the green space environment played a mediating role and indirectly suppressed the direct effect of green space on mental health. These findings enrich knowledge of the mechanisms between green space and mental health.

The results of this study can inform policies promoting the use of green space. Specifically, governments should provide more and better public service facilities, parks, and green space through community planning and construction. Government personnel should also aim to expand community organizations to encourage neighborhood interaction, thereby improving residents' mental health. In addition, given our finding that the relationship between the relative scope of green space and residents' mental health is mediated by residents' satisfaction with the green space environment rather than by its direct health effects, policymakers should consider not only the spatial distribution and quantity of such space but also residents' actual experiences and subjective satisfaction with green space environments when designing green space. Moreover, municipal governments should prioritize harmonious social interaction by allocating public green resources to improve residents' mental health and subjective well-being. As such, site selection should involve an evaluation of the potential merits of land value as well as the factors affecting residents' mental health and well-being. Decision makers can use this knowledge to improve the effectiveness of their mental health interventions as well. This study underlines the need to address subjective perceptions by revealing that a considerable proportion of the impact of mental health status can be explained by residents' satisfaction with green space exposure.

Despite its revelations, this study has several limitations that leave room for future work. First, a major limitation involved selection bias: the associations we have reported could be partially attributable to the selected city (i.e., Shenzhen) and the green space within it. Although we sought to minimize this constraint by considering respondents' socioeconomic and demographic characteristics, our estimations may nonetheless be biased. Moreover, urban green space is not equitably distributed in all cities. In Beijing, for example, green spaces are largely segregated by gated communities, and developers have transformed several public parks into community gardens or golf courses that residents cannot access for free. Such environmental disparity caused by spatial heterogeneity could greatly affect residents' satisfaction with green space. Accordingly, satisfaction may vary regionally, leading to variable mental health outcomes. A natural extension of this study would be to replicate our analysis of the relationship between green space and mental health in other geographical regions. Additional analyses, including taking all green space within a certain distance into account (64), can be performed to delineate the roles of residents' emotions on mental health. Second, our study involved a cross-sectional design and thus precluded clear causal inferences related to possible mediators. Compared with panel data, estimation performance based on cross-sectional data is lower. Longitudinal research could more firmly establish causality around the identified buffering effects of mental health. Third, we used "Quick Bird-2" high-resolution remote sensing image data, with a spatial resolution of up to 0.5 m, to calculate the ratio of green space in each case neighborhood. Using data sources with a higher spatial resolution would be intriguing. Fourth, global positioning system devices could be adopted to evaluate participants' time spent visiting green spaces more precisely than self-report measures. Fifth, because our work was exploratory, the research design was relatively simplistic. Other quality-based characteristics of green space (e.g., aesthetics, biodiversity, walkability, sport/play facilities, safety, and organized social events) have been suggested to consider when predicting green space use (65) and may have influenced our analyses of the mediating role of residents' perceived satisfaction. It would be interesting to investigate whether such factors can lead to causal relationships, especially when some of them are controlled for during mediation analysis (66). Sixth, scholars should continue to explore how demographic variables such as personal race, age, and income contribute to green space use and associated mental health benefits (6, 27). We encourage additional investigation into how and why the effects of green space on mental health vary demographically. We also recommend that researchers consider the impacts of environmental interventions on individuals' mental health outcomes. Doing so may offer valuable insight into which types of residents will benefit most from green space to help stakeholders exploit these advantages more fully. Subsequent work should shed more light on the mechanisms behind the association between green space and mental health and to what extent perceived emotions play causal roles in these relationships.

DATA AVAILABILITY STATEMENT

The original contributions presented in the study are included in the article/supplementary material, further inquiries can be directed to the corresponding author/s.

ETHICS STATEMENT

Ethical approval was not provided for this study on human participants because Ethical approval for this study was not required in accordance with local legislation and national guidelines. The patients/participants provided their written informed consent to participate in this study.

AUTHOR CONTRIBUTIONS

TZ made substantial contributions on the research idea, research design, and English proofreading. YQ contributed to this paper on data acquisition, audit of data analysis, discussions, and implications. ZC contributed to this paper in research background, data analysis, manuscript drafting, and reference cross-checking. YC contributed to this paper in data interpretation, manuscript corrections, and response to the reviewers. All authors contributed to the article and approved the submitted version.

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Greenway Cyclists' Visual Perception and Landscape Imagery Assessment

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Greenway is a kind of corridors in the city that takes natural elements as the main constituent foundation and connects open spaces with functions such as leisure and recreation. The assessment of the built greenway is a review of the past construction experiences, and it is also a supplement and improvement to the future greenway planning concept system, which has important academic and application value. This study will explore how greenway design factors influenced the local cyclists' perception of the landscape using on-site questionnaire and photo rating method. The results indicated that greenways with continuous cycling paths, high security awareness, open landscapes, and rich human activities evoke positive perceptions. Among the visual elements, natural elements such as plants and sky are more favorable than artificial elements. The research results show that the formation of greenway cyclists' landscape imagery is affected by visual perception elements, which suggests that special consideration should be given to the laws of cyclists' mental perception when designing greenways.

Keywords: visual perception, landscape imagery, greenway design, cycling, assessment

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INTRODUCTION

Environmental behavior studies and environmental psychology consider the interrelationship between people (users) and the physical (built) environment (Gifford, 1987; Moore, 1987; Yulian and Zhengfan, 2001; McCormack et al., 2010). This allows spatial environment research to be combined with environmental factors and cognitive behavior mechanism exploration, conducive to providing user-friendly design suggestions for space optimization and promotion.

The concept of greenway originated in the 1970s (Charles, 1995). It refers to corridors of linear green open space with ecological significance, leisure and recreation functions, and even historical and cultural values. Since 1985, Chinese scholars have successively introduced foreign greenway concepts, values, and practices, and have begun to make suggestions for improvement of urban green space systems and ecological infrastructure based on the principles of landscape ecology (Bin, 1985; Jianshuang and Fei, 2010; Kairan, 2010). Since 2009, China's Pearl River Delta area① has been constructing greenways, a trend that has since expanded into Beijing, Wuhan, Chengdu, Changsha, and other cities (Xinhua News Agency, 2019).

Previous studies of greenways focused mainly on ecological network systems (Flores et al., 1998; Jim and Chen, 2003). However, with more attention given to the health of urban residents, research on environmental factors and healthy behaviors has begun to increase, and the fitness and sports function of the greenway has received more attention (Fitzhugh Eugene et al., 2010; Tully Mark et al., 2013; Frank et al., 2019; Hongyun et al., 2019). Research focusing on greenways for cycling space and other sports activities needs to be urgently undertaken.

Current research into the greenway cycling environment mainly relies on the comprehensive analysis of cycling environment element assessment and subjective assessment of cyclists (Tsui-Yun and Yann-Jou, 2007). There are three shortcomings in the research on greenway cycling (Moore, 1987) insufficient attention to the difference between greenway cycling and other physical activities (i.e., jogging, running) (Gifford, 1987) insufficient attention to the difference between greenway cycling and other types of cycling; and (Yulian and Zhengfan, 2001) the impact of landscape elements on cycling. In particular, the quantitative analysis of environmental elements of perception assessment is insufficient (He et al., 2019; Liu Song and Wanchen, 2020). The small number of case studies that fully consider the cyclist's behavior and assessment perception limits the assessment of the cycling environment[②].

China's official policy[③] specifies the facility configuration requirements in greenway design but lacks a scientific assessment system for the landscape quality generated by these elements. In essence, the understanding of the relationship between the quality of landscape design with users' perception and assessment is still insufficient. This study investigated the influential factors and patterns of a cyclist's visual perception of the greenway landscape to enrich the design theory and construction guidelines of urban greenways.

CORE CONCEPTS

Visual Perception

Visual perception is a physiological function, which relies on visual senses and information processing organs (Rogers, 2011). Visual perception is the main source of information, including color, shape, depth, and dynamics. This information is processed and interpreted to develop a deeper understanding of the objective world (Gogel, 1962; Wei, 2006; Lengen, 2015). Visual perception is accompanied by subjective correction of information translation, a topic that psychology and brain science scholars are committed to research (Tayal, 1972; Pylyshyn, 1999).

In the landscape field, the study of visual perception fundamentally explores the essence of beauty (favorability, attractiveness, or preference). Visual esthetic quality entails the philosophical debate between Platonic and Kant-style beauty[④] (Terry and Wither, 2001; Wang et al., 2006), thus promoting the fusion of perception research on subjective judgment and objective characteristics (Lange and Legwaila, 2012). The study of perceptual laws (Shen, 2005) has advanced steadily with improvements in science and technology, as new technologies, such as ophthalmography and holographic projection, are applied to this research field.

Landscape assessment is inseparable from analysis of multi-sensory elements, especially the visual elements (Gan et al., 2014). In terms of visual perception, there are two research difficulties. The first is the identification of visual perception elements (Yanga et al., 2009). Not all types of visual information can be accurately identified. Advances in image recognition technology mean surveys use photo data for machine analysis instead of traditional manual identification (Lai et al., 2014; Gebru et al., 2017), which allows the current mainstream research to obtain basic information such as color, attribute, quantity, and scale. Jun analyzed the calculation method of the green view index and proposed that the distance between the observer and the green environment could affect the final value (Bin-yi, 2015). This means that future research will be more closely linked with psychology and brain science to obtain more reliable data (Coltheart, 2004). The other research difficulty is the quantification of visual perception results. Liu's research explained the principle of subjective perception in the translation of objective environmental information of landscapes. He established a quantitative assessment standard and index system and proposed a technical method for measuring and simulating landscape openness and serene ranking (Liu et al., 2017). This work plays an important role in the further construction of a multi-level weight evaluation system. There is still a lack of scientific and quantitative models, and further research on neurophysiological technology and brain imaging technology is needed (Taira, 2017).

Cycling is a type of motion and greenway cyclists often cycle with a speed of 10–25 km/h, so that the greenway becomes a fast-moving landscape (Jian, 2017). This differs from the exploration of moving objects in previous research on visual perception (Sachsenweger, 1986; López-Moliner et al., 2004), as cyclists are the moving subjects. The relationship between the environment and the cyclists can also change with the cycling speed, viewing direction, and angle of sight (Liang et al., 2002; Santillán and Barraza, 2019).

Landscape Imagery

The concept of landscape is the whole of its form and function, with the totality of subjective and objective interaction, and being perceived is one of its inherent attributes[⑤]. Whether in eastern or western culture, the earliest meaning of landscape derives from visual esthetics. During the Renaissance, landscape gradually became an esthetic object from the background of human existence, and natural landscape gardens became one of the expressions of human artistic esthetics (Pedroli and Pinto-Correia, 2006; Stobbelaar and Pedroli, 2011). In 1935, Chinese silviculturist Chen Zhi's *Introduction to Gardening* introduced the Japanese character "landscape" into China. Chen Zhi's work described the basic meaning of traditional gardens and landscapes and introduced characteristics of visual esthetics (Zhi, 1935; Guang-si, 2006). Landscape imagery is a composite concept and an important influence in the conception and formal expression of landscape design, audience perceptual experience, and consciousness (Michael and Stephen, 1994).

Research on landscape imagery mostly focuses on the perception of physical landscape environment, reflecting a consensus regarding landscape consciousness (Nohl, 2001; Lei, 2014). Ding believes that the generalization and abstraction of specific landscape images can reflect the local cultural and historical characteristics and can be understood as a specific "landscape imagery unit" of the place (Shao-gang, 2011).

Landscape imagery assessment research methods commonly use social investigation and statistical analysis, such as importance-performance analysis (O'Leary and Lee, 2016) and semantic differential (SD) methods (Cao and Liang, 2004). These methods try to translate the viewers' perception results into quantitative indicators through semantic descriptions.

Considering that perceptual evaluation is a kind of subjective evaluation, research will generally adopt public preference surveys to enhance the effectiveness of evaluation (Clay and Daniel, 2000; Kalivoda et al., 2014; Gao et al., 2019). Xu uses the SD method and scenic beauty estimation to explore the esthetic differences underpinning landscape assessment and proposed that landscape design should pay more attention to the diversity of user types, considering both functionality and esthetics (Wang et al., 2006; Da-wei, 2014; Vessel et al., 2018).

In the study presented here, the differences in the elements of the perception results of different observers will be summarized, some image structure models will be drawn, and the overall image space cognition results will be further explored (Chaolin and Guochen, 2001; Wei, 2006; Yuehao et al., 2019).

MATERIALS AND METHODS

Study Area (Site)

The 102-km Eastlake Greenway, located in the city center of Wuhan Eastlake Ecological Tourism National-level Scenic Area[⑥], is the "ecological green heart" for locals.

All the loops of the greenway connect the five major areas of the overall scenic area where one can enjoy a variety of natural sceneries: mountains, lakes, forests, wetlands, islands, and fields (Wuhan Donghu Green Road Operation Management Co., Ltd., 2019). UN-Habitat described Eastlake Greenway as "China's demonstration of improving urban public space." (UNHABITAT, 2019) Contrasted with countryside greenway, it is a unique city greenway with entrances distributed over three districts in Wuhan for easy access for its citizens (Chao and Xuan, 2017). Our preliminary studies showed that more than 60% of users chose to cycle along the greenway (He et al., 2019).

The greenway is divided into two phases (Phase I finished in 2016, and Phase II in 2017) (**Figure 1**). The research object in Phase II consists of three parts: Baima Road, Tingtao Road, and Senlin Road (Wuhan Donghu Green Road Operation Management Co., Ltd., 2019)[⑦].

Baima Road is 14.7 km and mainly includes two islands and a lake-long embankment with miles of peach blossoms. This area was designed as a city waterfront ecological art zone and provides an important image of an urban portal because of its location. Tingtao Road is 9.02 km, and was designed as an urban garden, combining historical culture with natural scenery for public fitness and enjoyment. Senlin Road is 26.22 km and located in a natural forest park. It connects multiple botanical gardens and a series of outdoor activity areas.

Phase II is described as wilder and fun in that it is more closely connected with nature than Phase I. The visual landscape is more beautiful, and the cultural connotations are more abundant. In terms of the cycling experience, Phase II has more gentle trails, the natural ecology is plentiful, and there are a greater variety of route options for ecological exploration and reflection (Hongxia and Jingang, 2019; Xiao, 2019).

Methods

Based on the research purpose of exploring the relationship between greenway cyclists'visual landscape elements and imagery perception assessment, this study mainly used comprehensive landscape analysis and assessment (Jiong-wei et al., 2010). The overall evaluation belongs to post-use evaluation (POE) and case empirical investigation. The main research methods can be introduced in three stages:

The first was to collect information through random questionnaire surveys, including cyclists' basic socio-economic attributes, and greenway use characteristics – especially cycling activity characteristics during specific time periods (working days and non-working days) – for subsequent observation and comparison.

Second, for the study of visual landscape elements, this study mainly considered the impact of the environment on cycling activities. Thus, we did not focus on the ecological nature of the landscape, or the combination of vegetation, biodiversity, and accessibility studies. The compound effects of non-visual factors were not considered, as we rather tried to avoid the interference of these factors (choosing survey days with similar weather conditions). Therefore, in addition to recording the types and characteristics of the elements, the observation of visual elements itself contained the subjective assignment of the investigator, especially esthetic imagery perception (Kongjian, 1986). Past research typically used comprehensive qualitative and quantitative assessment (Genoveva, 1995; Gobster Paul, 1999; Akbar and Hale, 2003). Specifically, before the survey, the effect of the visual landscape was clarified using pictures with the upper and lower limits of the score, and scores were assigned based on this reference. In addition, with the help of image analysis technology and expert scoring methods, computer programs were used to analyze and calculate the visual elements of the on-site (node) photographs taken by the investigators on the field survey. At the same time, planning and design professionals scored the visual quality of these photographs as a reference for evaluation.

In our survey, visual elements were classified into natural elements and artificial elements (**Table 1**). Each element was scored and semantically described, including shape, color, attribute, scale, and intuitive feeling. Semantic statistical node description was used to determine the type of information that will receive more attention when scoring quality in the visual landscape.

Third, the SD method was mainly adopted for the evaluation of image perception (Junhua, 2004) and cognitive map technology (Lynch, 1960). Image perception described the subjective feelings of the cyclists in the photographs of the nodes with semantic word pairs, and assigned specific scores to obtain their quantitative perceptual evaluation. This is actually the establishment of a "transformation box" that converts

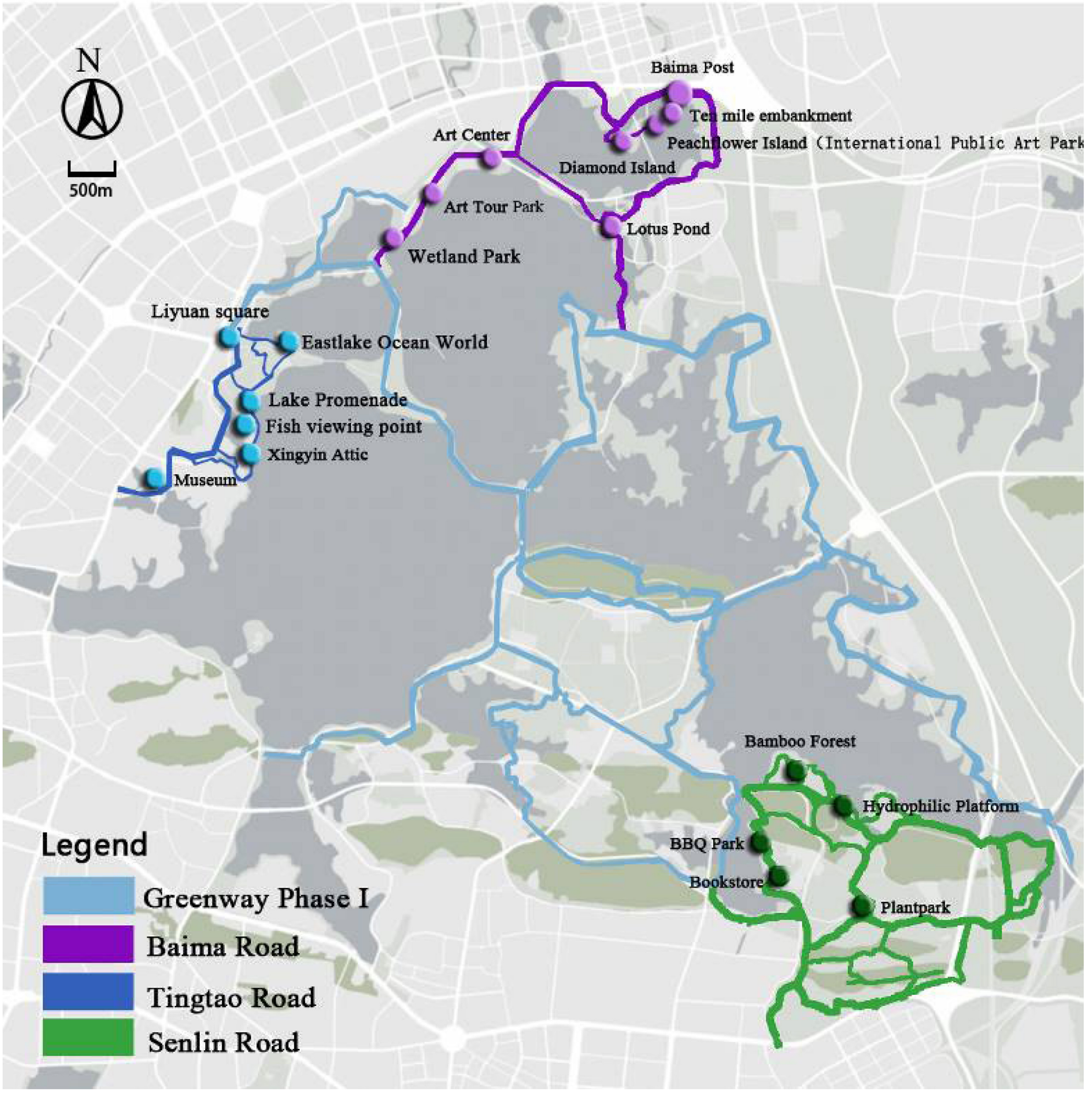

FIGURE 1 | Eastlake Greenway Location and Construction (Nodes indicate locations of scenic spots).

cognitive feelings that are not easily expressed – including semantic adjectives, ordering of judgments, value orientation, and cultural associations – into relatively visible, computable scores (Tveit et al., 2006). A five-point assessment scale was used in this research, with scores of -2, -1, 0, 1, and 2, representing "very poor," "poor," "average," "good," and "very good," respectively. The scoring was applied to 22 assessment items (**Table 2**), and the final score was divided into eight intervals (categories) from lowest to highest. A cognitive map was used with interviewees who were asked to mark the most memorable spatial points on the map with text information removed, and to try to describe and evaluate these anchor points[⑧], before finally superimposing these nodes on the space to form an imagery structure.

Through the greenway cyclists' visual landscape elements and imagery perception assessment, a spatial correspondence was established and used to explore whether there is a relationship between the two, and whether there are differences in the degree of influence of different types of visual landscape elements. This stage will simply make preliminary judgments using statistics (SPSS correlation analysis) without in-depth exploration.

Data Collection

Data collection was mainly completed through field surveys that investigators chose to undertake on working and non-working days in May 2019[⑨].

A total of 64 professional students were divided into two groups, a recording group and a questionnaire interview group.

The recording group took 1289 photographs of 678 nodes and evaluated features from a cycling perspective[10]. To ensure a sufficient number of pictures, the node photographs needed to contain records of at least every 100 meters. Therefore, it was found that there are differences in the continuity of the cycling routes (**Figure 2**). There are some routes in the three greenways likely to affect the subjective feelings of cyclists because of the slope, pruning, and impassable conditions such as road maintenance. Professional students also took 672 node pictures with higher visual quality based on their own judgment. The questionnaire interview group randomly distributed questionnaires and cognitive maps to greenway cyclists to obtain basic user information and use characteristics. They focused on recording the visual and semantic description of the nodes drawn by the cyclists. In the end, 237 valid questionnaires and 129 cognitive maps were obtained[11].

TABLE 1 | Visual landscape element evaluation table.

Node number:□	Type	Score& description *Suggested description
Natural Elements	Mountain	*Height, slope
	Water	*Color, clarity, openness
	Plants (i.e., trees, shrubs, lawns, flowers)	*Richness, matching degree, sense of space
	Animals	*Type, psychological feeling
Artificial Elements	Facilities (Environmental, Rest, Guide facilities)	*Type, fashionable
	Vehicles	*Quantity
	Roads	*Width, material, color, straightness, slope
	Fence or block	*Function, form, psychological feeling
	Buildings (commercial, public service)	*Function, form, psychological feeling
	Landscape sketches (sculptures, water features, lights, flower stands, scenery walls, leaking windows)	*Type, fashionable
	Parking, roadblocks, telephone poles	*Type, fashionable
Pedestrians	Behaviors	*Quantity

RESULTS

User Characteristics

User characteristic data comes from questionnaire interviews that included four main parts: basic information about cyclists, characteristics of greenway use, comprehensive scoring and semantic description selection, and cognitive maps of the three greenways.

Basic Information About Cyclists

Based on previous studies and our own observations, most cyclists were local citizens. Additional information, such as gender, was collected through the questionnaires (**Table 3**). Slight differences in gender, age, and work attributes may reflect variations in the public's enthusiasm for the greenway space and the experiences it offers for all ages and interests.

The statistical results show the gender ratio for cycling on weekends is very similar, while more men cycle on workdays than women. The 18–40 age group comprises the main user group, and most people were non-professionals, which conforms to general survey expectations.

Characteristics of Greenway Use

Through the questionnaires, a simple understanding of the cyclists' behaviors was obtained (**Table 4**). The scenic area service coverage is expansive, and the cyclists sampled were in a limited area. The main functional needs of the greenway specified by the cyclists were physical exercise and enjoyment of beautiful scenery. Due to differences in functional requirements, work schedule, transportation costs, and riding frequency were higher during the weekends when the time spent cycling for exercise was usually 1–2 h. The viewing route covered by these cyclists tended to be relatively long, and the speed was relatively fast.

TABLE 2 | Semantic assessment items and adjective pairs.

Assessment items	Semantic adjective pair	Score (−2∼2)	Assessment items	Semantic Adjective Pair	Score (−2∼2)
Sense of Space	Open∼Closed	□□□□	Naturalization	Natural∼Artificial	□□□□
Lightness	Bright∼Dark	□□□□	Vegetation Cover	High∼Low	□□□□
Layering	Layered∼Blurred	□□□□	Esthetic Sense	Beautiful∼Devoid of Beauty	□□□□
Rhythm	Strong Rhythm∼Weak Rhythm	□□□□	Coordination	Coordinated∼Disharmony	□□□□
Ambiguity	Atmosphere∼No Atmosphere	□□□□	Pleasure	Pleasant∼Unpleasant	□□□□
Color Richness	Colorful∼Monochrome	□□□□	Closeness	Close∼Alienated	□□□□
Continuity	Continuous∼Discontinuous	□□□□	Impression	Impressive∼Weak Impression	□□□□
Neatness	Accordant∼Messy	□□□□	Change	Variable∼Lack of Change	□□□□
Attractiveness	Attractive∼Unattractive	□□□□	Quietness	Quiet∼Noisy	□□□□
Vitality	Living∼Lifeless	□□□□	Dynamic	Dynamic∼Not Dynamic	□□□□
Freshness	Novelty∼Ordinary	□□□□	Security	Safe∼Unsafe	□□□□

**Score“-*2, -*2, 0, 1, 2” represent “very poor, poor, general, good, and very good”.*

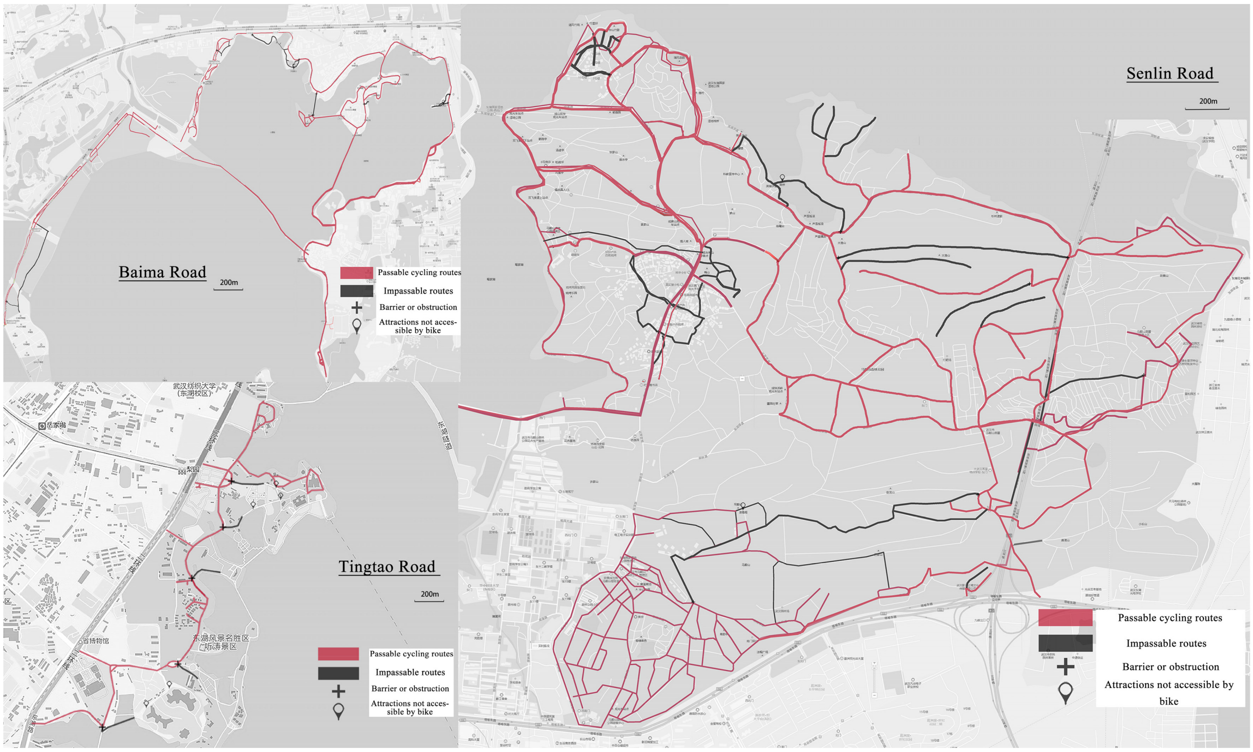

FIGURE 2 | Baima Road, Tingtao Road and Senlin Road portable routes.

TABLE 3 | Basic information of cyclists.

Category	Weekend			Workday		
	Baima road	Tingtao road	Senlin road	Baima road	Tingtao road	Senlin road
Gender						
Female	44.12%	40.7%	40.3%	29.2%	33.3%	41.1%
Male	55.88%	59.3%	59.7%	70.8%	66.7%	58.9%
Age						
Under 18	0	3.7%	8.33%	4.17%	0	3.57%
18–40	73.5%	88.9%	75%	62.5%	87.5%	75%
40–60	20.58%	7.4%	16.67%	20.84%	12.5%	17.86%
Over 60	5.88%	0	0	12.5%	0	3.57%
Occupation						
Non-design related	94.1%	88.9%	84.7%	66.7%	83.3%	78.6%
Design related	5.9%	11.1%	15.3%	33.3%	16.7%	21.4%

More leisurely cycling activities were influenced by the greenway nodes, rest facilities, interaction with the environment, and other behaviors interspersed throughout the leisure cycling excursions, when the ride time was relatively short.

Comprehensive Scoring and Semantic Description Selection

Cyclists' perception scores were determined over a relatively short time, so their recorded experience tended to be more general, resulting in a rough estimate of their overall perception of the landscape (**Table 5**). The results revealed some common elements of cyclists' perceptions among the three roads: an appreciation of the greenway's beautiful natural scenery and the good air quality for certain social leisure activities. Adjectives used to describe the cyclists' experience of the landscape frequently included words such as "pleasure," followed by "close" and "vibrant." Cyclists generally believed that the first thing that attracted them during their cycling excursion was the presence of rich natural elements, followed by the designed plantings/gardens and waterfront areas. Most cyclists believed the greenway to be unique in its beauty, superior to typical parks and sports venues.

TABLE 4 | Characteristics of greenway use.

Category	Weekend			Workday		
	Baima road	Tingtao road	Senlin road	Baima road	Tingtao road	Senlin road
Source						
Less than 10 km	88.24%	70.4%	88.9%	87.5%	80.4%	75%
10–30 km	5.94%	25.9%	6.5%	12.5%	11.3%	3.57%
Over 30 km	5.82%	3.7%	4.6%	0	8.3%	21.43%
Frequency						
More than 3 times a week	23.53%	7.41%	16.67%	33.3%	29.17%	25%
About 1–3 times a week	20.59%	22.22%	20.83%	20.83%	4.17%	10.71%
About once a week	23.53%	22.22%	27.78%	8.33%	12.5%	17.86%
Less than once a week	2.94%	48.15%	34.72%	37.5%	54.2%	46.43%
Goal(Multiple choice)						
Exercise	76.47%	55.56%	66.7%	45.8%	37.5%	57.14%
View	67.65%	61.2%	48.6%	45.8%	41.7%	49.91%
Others	9.86%	23.21%	13.6%	12.67%	11.67%	11.79%
Riding time						
Within 30 min	3.88%	14.81%	12.5%	8.33%	33.3%	23.21%
30–60 min	23.53%	44.44%	39.11%	29.71%	37.5%	22.63%
60–120 min	46.12%	11.11%	26.65%	26.6%	12.6%	25.71%
More than 2 h	26.47%	29.63%	21.74%	35.36%	16.67%	28.45%

TABLE 5 | Cyclist's comprehensive scoring and semantic description selection.

Category	Weekend			Workday		
	Baima road	Tingtao road	Senlin road	Baima road	Tingtao road	Senlin road
Average rating (Full score is 10)	7.86	7.62	7.95	7.75	7.71	7.81
Best service top 3	①Natural scenery, ②air quality, ③social leisure	①Natural scenery ②air quality ③social leisure	①Natural scenery ②air quality ③social leisure	①Natural scenery ②air quality, ③social leisure	①Natural scenery ②air quality ③social leisure	①Natural scenery ②air quality ③social leisure
Adjective words used more	①Pleasant ②close ③vitality	①Pleasure ②closeness ③vitality, freshness	①Pleasant ②close ③vitality	①Pleasant ②close ③vitality	①Pleasant ②close ③vitality	①Pleasant ②close ③vitality
Attracting visual elements	①Natural elements ②plant colors and species ③waterfront design	①Natural elements ②plant colors and species ③waterfront design	①Natural elements ②plant colors and species ③waterfront design	①Natural elements ②plant colors and species ③waterfront design	①Natural elements, ②plant colors and species ③waterfront design	①Natural elements ②plant colors and species ③waterfront design
Characteristic feeling	61.8% can feel the unique beauty	77.8% can feel the unique beauty	75% can feel the unique beauty	66.7% can feel the unique beauty	100% can feel the unique beauty	76.8% can feel the unique beauty

Cyclists' Cognitive Maps

After superimposing the image nodes and paths drawn by the interviewed cyclists, a preliminary imagery space diagram was obtained (**Figure 3**). Many had difficulties in identifying the physical location of landscape imagery and were only able to provide a fuzzy spatial scope area. Others were quick to identify the impression of the pictured landscape node and were able to provide a detailed description of the landscape characteristics and their feelings related to the scene.

Features of Landscape Visual Elements

With the help of an App, "Cats' Eye Quadrant" ⑫, we were able to quantify the number of people, number of motor vehicles, and the area rate in photographs (**Table 6**). The number of vehicles can reflect on-site activity conditions and the degree of motor vehicle interference. The area rate reflects the visual structure of the landscape. Relationships between node data and equidistant record data can also reflect a given rider's preferences.

From the results of the photo analysis, the average green viewing rate of the three green roads reached 49.76%, the

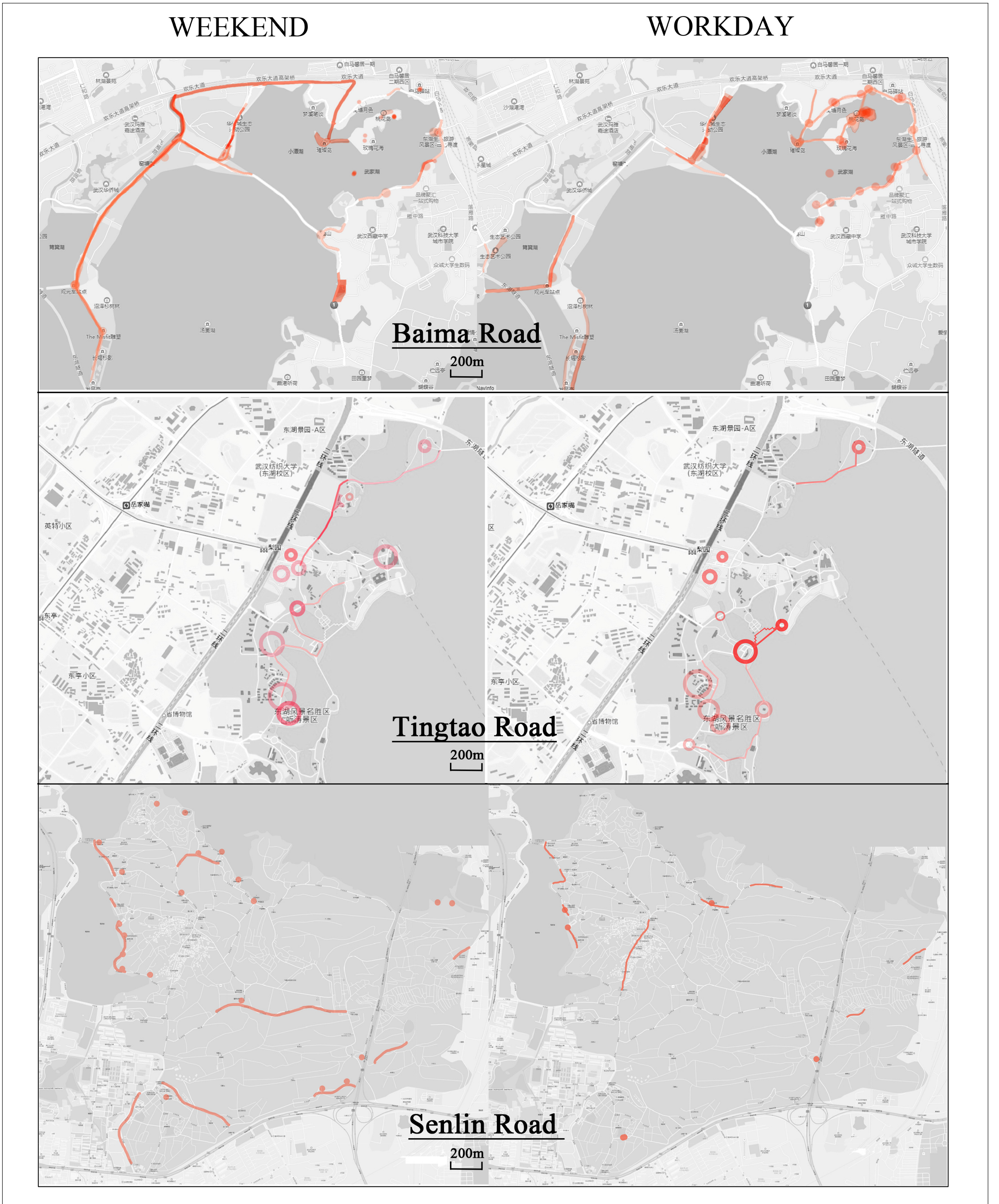

FIGURE 3 | Baima Road, Tingtao Road, Senlin Road Cognitive map. *Color depth indicates the degree of impression of the landscape in the area.

TABLE 6 | Landscape elements indicators.

Study Object	Day	Observation type	Number of photos	Number of people	Number of motor vehicles	Building area ratio(%)	Green rate(%)	Road area ratio(%)	Sky area ratio(%)
Baima Road	Workday	Isometric Average	86	0.5	0.16	2.97	39.3	29.28	20.93
		Node Average	115	0.12	0	5.97	50.24	9.56	24.11
	Weekend	Isometric Average	85	2.1	0.08	5.2	40.32	20.45	22.54
		Node Average	112	0.63	0.02	5.49	53.68	9.23	19.52
Tingtao Road	Workday	Isometric Average	40	1.98	1.33	9.08	45.11	23.38	5.77
		Node Average	23	1.86	1.88	5.91	48.85	17.77	0
	Weekend	Isometric Average	39	3.97	0.97	7.65	48.85	17.88	8.25
		Node Average	20	4.22	1.43	4.89	57.55	12.25	10.01
Senlin Road	Workday	Isometric Average	181	1.22	0.29	3.33	51.85	20.64	14.76
		Node Average	203	0.49	0.19	5.68	54.21	14.95	15.96
	Weekend	Isometric Average	180	2.17	0.5	3.81	51.14	18.6	15.41
		Node Average	205	1.08	0.21	4.76	55.98	14.25	15.65

sky rate was 14.4%, the road 17.35%, and the building at about 5.4%. Natural elements occupy a dominant position in the landscape vision, indicating that the overall quality of the landscape on the greenway cycling route is relatively good, but at the same time the lowest green viewing rate was 39.3%. This may be related to the fact that Baima Road is still in the optimization period, and some street trees have only been planted for a short time and their growth is limited. Tingtao Road, which was originally a private garden, is now easily accessible by visitors and is known for its historical and cultural heritage. However, the high frequency of motor vehicles may interfere with slower-moving activities. Additionally, this area did not show significant variation in relation to the time period. Senlin Road is the longest and most complex trail in this study, and also the area with the most abundant landscape. The data show that activities varied considerably among equidistant records and node photographs. Combined with its landscape factor ratio, the overall green viewing rate was high, as expected due to the expansive natural landscape of this route.

Correlation Analysis of Landscape Perception

Score and Rider Attributes

The social characteristics of cyclists indicated that the main beneficiaries of the greenway are still primarily the local population and that preferences with respect to gender, age, and career are evident (**Table 7**). Male cyclists gave higher scores than women, indicating a potentially higher stress level for women than men that was not resolved during the greenway experience. Overall assessments by elderly and very young users were higher than those of young to middle-aged users. Middle-aged participants, as the main users, wanted more from their landscape environment. The overall low score given by professionals and design-related cyclists indicated their need for a greater range of experiences, longer cycling routes, and the potential incorporation of landscape features that allowed for special cross-regional activities.

TABLE 7 | Cyclists' assessment scores and features.

Features Scores	Features	3–5	5–7	8–10	Total
Gender	Male	0	57	136	193
	Female	11	23	45	79
Career	Related to Design	12	34	125	171
	Not Relevant to Design	11	45	45	101
Age	Below 18	0	0	12	12
	18–25	11	45	22	67
	26–30	0	11	23	34
	31–40	0	23	34	67
	41–50	0	0	45	45
	51–60	0	0	12	12
	60+	0	0	34	34

Score and Node Spatial Distribution

By assigning a score for each node to the space, a node assessment chart was obtained covering the three roads for weekends and workdays (**Figure 4**). The chart visually reflects the nodes that are more likely to have left a positive visual impression.

Judging from the spatial planning characteristics of the three greenways, they all make full use of the lakeside shoreline, especially Baima and Tingtao. Many landscape nodes are densely distributed in the waterfront area. Setting the cycling route in the waterfront area ensures sufficient visual openness. Therefore, the convex side of Baima has higher average scores than the concave side, and the whole of Tingtao is relatively homogeneous. At the same time, the waterfront area node of Senlin will be higher than the overall level of the mountain area.

In the design of the greenway environment, more public art sculptures are arranged on both sides of the Baima greenway route, which will also greatly attract the attention of cyclists and increase the attractiveness of the area. The Tingtao greenway route is surrounded by urban cultural public buildings (museums, libraries), entertainment venues (ocean parks, playgrounds), and residential buildings, yielding a relatively high vitality index that also increased the overall score. The design of Senlin also has these features. The western

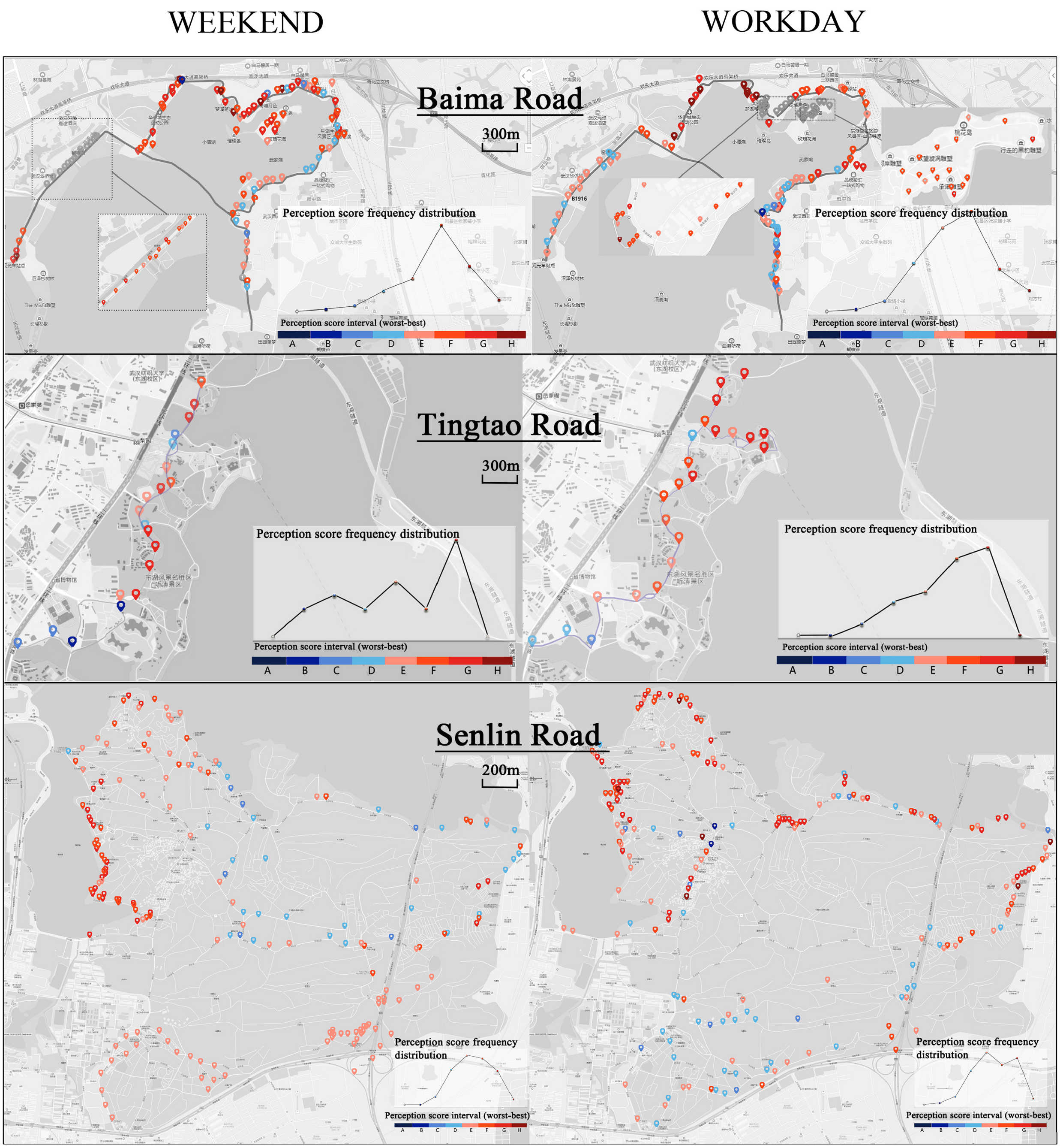

FIGURE 4 | Baima, Tingtao, and Senlin Road weekend and workday node assessment spatial distribution map.

waterfront area is not only close to the university campus living area but also has creative bookstores, barbecue camping areas and other places to enhance vitality. In contrast, the east side is bounded by a busy road and the landscape feel and atmosphere of activities are both relatively poor.

Comparing the data on weekdays and weekends, it was found that the nodes in the middle and high scoring segments were appropriately reduced on weekends, and the degree of aggregation of nodes was appropriately increased. From the interview survey, it can be deduced that this is due to the crowding and lack of security caused by the increase in the number of weekend activities.

Scores and Visual Elements

Analysis of the pictures of the typical landscape nodes of the three roads (**Figure 5**) revealed that the proportions and positions of natural features conformed to the laws of graphical esthetics (Klix, 2001; Wagemans et al., 2012), and

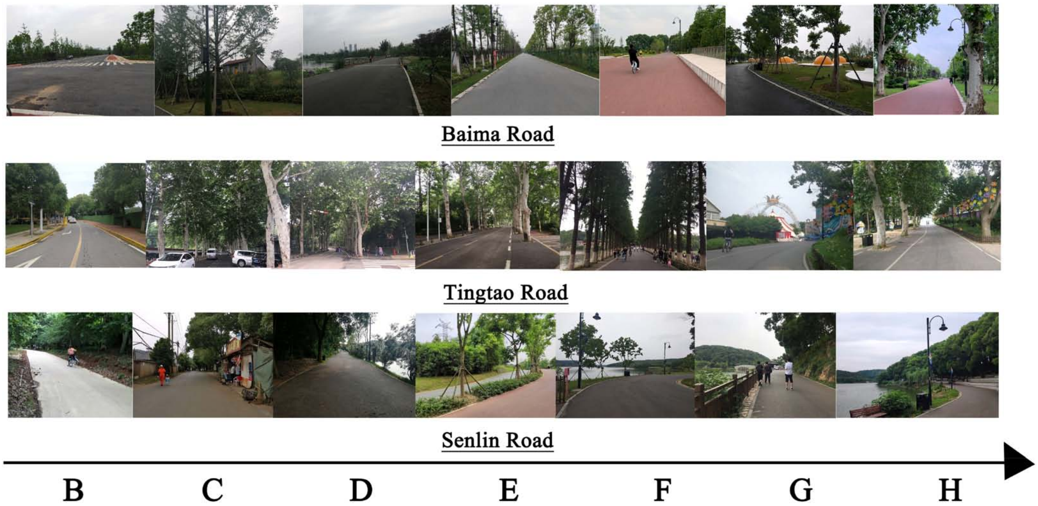

FIGURE 5 | Typical landscape of different segments.

the openness and brightness of a space objectively affected the visual perception of cyclists (Zhang et al., 2019). Structures with a sense of design can form stimuli in the scene, prompting cyclists to engage in conditioned reflection and cognitive imagery (Momtaz and Daliri, 2016).

Further statistical analyses of the feature area visitation rate and scoring results (**Tables 8**, **9**) were conducted to determine the internal relationship among factors. A negative correlation was identified between the perception of greenness and the number of cars, whereas building area and number of cars were positively correlated.

Our statistical results show that the green viewing rate had the greatest influence on the overall perception score. The remaining factors did not differ significantly in their influence, although the influence of roads and sky was high. Thus, for the overall landscape structure, green space and its related feelings had the greatest influence on visual perception (Kaplan and Kaplan, 1989; Maas et al., 2006; Jiang et al., 2014; Lindala and Hartig, 2015).

Imagery and Perception Elements

To further study which factors influenced the final perception score, the scores for each node in the three roads were analyzed separately (**Figure 6**), and the factors influencing different imagery structures were examined.

The Baima Road landscape makes full use of natural resources such as the mountains and water and the core position of the island in the lake. Thus, the entire cycling experience forms a coherent imagery space. As can be seen from the frequency chart, cyclists evaluated their overall sense of space, security, and coordination, followed by impression and beauty, and perceived deficits in the natural quality of the experience. According to the semantic description of typical nodes in each segment, the reasons for low scores were a lack of security (e.g., wide roads and motor vehicles) and disharmony in the landscape (e.g., architecture, municipal facilities). Interesting and novel sculptures, parking facilities, and rest facilities were key elements that appealed to cyclists. In addition to considering the road itself, cyclists also noted whether the surrounding environment showed change and natural rhythms, natural culture with rich connotations, and ecological diversity.

Tingtao Road is a traditional humanistic park-style greenway. Cultural resources are used to enhance the sense of experience and participation. Thus, cyclists can continuously enjoy the cultural scenery as forming a linked imagery space. The assessments for a sense of space, atmosphere, and coordination were high. The degrees of naturalization, quietness, and overall public opinion were more variable, revealing greater differences. Although vegetation cover was well recognized, the assessment of its natural quality was not high, indicating that the greenway landscape maintenance and restoration were not sustained. Combining this information with the analysis of the semantic description of typical nodes, we concluded that cyclists generally believed that plant maintenance management was poor. Some sections of the environment were described as "claustrophobic" and "not secure," with buildings obscuring the view. Neat and micro-transformed beautification nodes were preferred.

Cyclists in Senlin Road appeared to pay more attention to the route design and natural sense. Leisure activities and artistic sculptures enriched the cyclists' experience. Similar nodes combined with each other to form a fragmented imagery space. Cyclists gave high scores to the sense of space, followed by vegetation cover and attractiveness, with low scores for naturalization, freshness, dynamics, and security. Thus, the overall landscape design takes full account of the use of natural resources (Benjamin and Roland, 2002); however, certain deficits were evident in the humanized design and subsequent management. Combined with the semantic description, these data show the engineered structures and traffic facilities within the overall landscape were unsatisfying to cyclists. The cyclists preferred dedicated bicycle lanes, an improved route marking system, a wide field of view, and rich plantings/green space.

TABLE 8 | Analysis of net correlation of objective factors.

	Number of people	Number of motor vehicles	Building area ratio (%)	Green rate (%)	Road area ratio (%)
Number of people					
Relevance	1.000	0.179	0.139	-0.245	0.216
Visibility		0.008	0.040	0.000	0.001
Df	0	216	216	216	216
Number of motor vehicles					
Relevance	0.179	1.000	-0.016	-0.133	0.275
Visibility	0.008		0.817	0.050	0.000
Df	216	0	216	216	216
Building area ratio(%)					
Relevance	0.139	-0.016	1.000	-0.440	0.024
Visibility	0.040	0.817		0.000	0.725
Df	216	216	0	216	216
Green rate(%)					
Relevance	-0.245	-0.133	-0.440	1.000	-0.456
Visibility	0.000	0.050	0.000		0.000
Df	216	216	216	0	216
Road area ratio(%)					
Relevance	0.216	0.275	0.024	-0.456	1.000
Visibility	0.001	0.000	0.725	0.000	
Df	216	216	216	216	0

TABLE 9 | Analysis of objective elements and scoring distance.

	Euclidean					
	Number of people	Number of motor vehicles	Building area ratio (%)	Green rate (%)	Road area ratio (%)	Sky area ratio (%)
Number of people	0.000	61.457	252.911	1382.211	421.621	515.130
Number of motor vehicles	61.457	.000	256.328	1396.189	426.911	527.689
Building area ratio(%)	252.911	256.328	0.000	1332.513	429.879	507.947
Green rate(%)	1382.211	1396.189	1332.513	0.000	1210.790	1147.075
Road area ratio(%)	421.621	426.911	429.879	1210.790	0.000	490.002
Sky area ratio(%)	515.130	527.689	507.947	1147.075	490.002	0.000
Overall rating	378.880	390.379	414.867	1218.705	468.670	475.413

According to the semantic description of the typical node, some sections (e.g., barbecue areas and parking areas) did not allow one to experience the greenway landscape. Thus, further management and consideration of the layout of commercial spaces in the scenic area are required. At the same time, rich vegetation and beautiful water scenery with a sense of designed construction (structures) were met with great enthusiasm by the cyclists.

Combined with the theory of spatial imagery, some impressive landscape node scenarios were in line with the principles of figure-ground, continuity, similarity (Arnheim and Shouyao, 1998), and fragments of broken imagery that ultimately constitute the imagery world of cyclists. Visual information was processed at psychological and esthetic levels (Valerie Gray Hardcastle, 2001). The cultural features of the imagery pattern can be considered in combination with the social characteristics of cyclists for further analysis.

DISCUSSION

Through the collection of indicators, it was found that cyclists offered positive assessments of the greenway landscape as a complex. In addition to choosing words with relatively positive meanings such as "pleasant, close, and vital," many cyclists also selected adjectives that focus on unsatisfactory environmental details. Different types of greenway visual landscape, sections, nodes of the same greenway, and even the same node in different time periods obtained different visual perception results, which fully confirms the subjective nature of visual assessment. The objective material environment still exists in a strongly subjective world – a view confirmed in this research (Zhou et al., 2014). However, the landscape imagery tended to produce a memory and cognitive blur due to the lack of effective venue memory for specific nodes along the way (Isola et al., 2011). In random interviews, the differences among the subjective values of cyclists

FIGURE 6 | Baima, Tingtao and Senlin Road weekend and workday nodes of Landscape perception levels.

were considerable, as reflected in their judgments of the same scene. Their judgments also tended to be full of emotionally evocative adjectives.

This paper presented innovative research on the correlation between visual perception and landscape imagery for cyclists in the greenway, and some preliminary results were shared. There are limitations to the research design: One is that there is a compound effect between vision and other senses, especially hearing (Mack, 1979; Xuan, 2019). Many respondents mentioned the sound of running water or the sound of birds, and eye movement experiments could be considered as one way of improving the inclusion of this aspect (Ren and Kang, 2015; Xiangyi, 2017). The second is the neglect of the differences in the continuity of cycling routes, just like in many previous studies using photographs (Shen, 2005; Gan et al., 2014; Gebru et al., 2017). The third is that the understanding of visual perception is not deep enough (Tveit, 2009). Fourth, some scholars have proposed that cultural background is also an influencing factor of image perception (Coltheart, 2004; Stobbelaar and Pedroli, 2011).

CONCLUSION

Landscape Imagery Structure

The innate natural conditions and landscape design of different greenways are perceived in unique ways depending on cyclists' visual perception. The meaning of the space will differ accordingly, leading to differences in the local landscape imagery assessment. The three types of greenways in Phase II form a coherent, connected, and scattered (fragmented) imagery structure in the minds of cyclists.

Influencing Factors of Assessment

The needs of cyclists are relatively abstract in visual terms. However, research can translate these needs into continuous paths, safe environments, open landscapes, and rich human experiences. Natural elements such as plants and the sky are intrinsically more popular than artificial elements. A greenway with more linear paths for better visualization of the road ahead is the most basic need of cyclists. Additionally, if the field of vision is open, various elements are perceived to be instantaneously more pleasant in contrast to more crowded social areas with people and/or animals. The combination of these elements has an impact on perceptual assessment.

Citations:

①The Pearl River Delta, located in the south-central part of Guangdong Province, is an important economic center in China.

②Based on the statistical results of research conducted by CNKI and WOS with the theme of "Greenway cycling."

③*Guidelines for Greenway Design and Planning(2016)*,published by Ministry of Housing and Urban-Rural Development of PRC,is to guide scientifically plan and design greenways, to improve the level of greenway construction, and give full play to the comprehensive functions of greenways.

④The difference between the two esthetic viewpoints is whether the essence of beauty is "appearing beautiful" or "really beautiful." Kant only regards "sensory perception as the art of yardstick" and believes that true beauty always implies its moral consciousness and moral emotions. There is a fundamental difference in "appearing beauty" that only inspires sensual pleasure.

⑤*European Landscape Convention*, published by European Landscape Convention of the Council of Europe,2000. Official website: https://www.coe.int/en/web/landscape/home.

⑥According to the *Regulations on Scenic Spots (2006)* of the PRC, national-level scenic areas are approved by the State Council to be announced as national-level scenic areas. It refers to an area with ornamental, cultural, or scientific value, relatively concentrated natural landscapes and cultural landscapes, and a beautiful environment for people to visit or conduct scientific and cultural activities.

⑦Eastlake has a long history, so many historical allusions are cited when naming the scenic spots and greenways: Baima refers the war horse of Lu Su, a famous general from the Three Kingdoms period of China in 208 A.D., was buried here; Tingtao scenic area was the private garden of the national capitalist Zhou Cangbai. After transformation, it became a public space, known as "One Scenery and One Garden, Listening to the Waves and Enjoying Pears"; Senlin means forests.

⑧Golledge believes that people's spatial cognition process is three-stage, and a specific "anchor points" plays a role in constructing an information system.Golledge R. Learning about urban environments[A]. In: Carlstein T, Parkes D, Thrift N. Timing space and spacing time, Vol.1[C]. London, Edward Arnold, 1979.

⑨The climatic conditions on the survey days are as follows: weekend days, cloudy, 17–26°C, relative humidity 70%, level 4–5 northeast wind; workdays, cloudy, 30°C, relative humidity 59%, southeast wind level 3–4.

⑩The cyclists' standard horizontal viewing angle was about 45°, and the vertical angle of view ranged from 26° to 30°.

⑪According to the statistical report of tourists on Eastlake Greenway, the average daily number of bicycle tourists is about 1375. The sampling rate of this random questionnaire survey is about 5.8%.

⑫"Cat's Eye Quadrant" is a survey and observation tool launched by the company *Urban Quadrant* based on mobile Internet and computational vision technology. The program can identify the number of people, vehicles, green viewing rate, sky rate and other indicators, where the green viewing rate and sky rate respectively refers to the area of the green plants and blue sky as a proportion of the total area of the photo. Company website: http://www.urbanxyz.com/.

DATA AVAILABILITY STATEMENT

The datasets generated for this study are available on request to the corresponding author.

ETHICS STATEMENT

Huazhong University of Science & Technology Human Ethics Committee waived the requirement for ethical approval for this study due to the following reasons: the study doesn't involve involuntary personal information investigations, and it doesn't involve any violation of the law. Written informed consent was obtained from the minor(s)' legal guardian/next of kin for the publication of any potentially identifiable images or data included in this article.

AUTHOR CONTRIBUTIONS

HH proposed the research direction. JL completed the experimental design and analysis and wrote the article.

XL participated in the field research and proposed the revision suggestion. YY participated in the field research and partial data analysis. All authors contributed to the article and approved the submitted version.

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Dynamic Changes in Community Deprivation of Access to Urban Green Spaces by Multiple Transport Modes

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Urban green spaces (UGSs) improve the quality of life of urban inhabitants. With the acceleration of urbanization and changes in traffic networks, it remains unclear whether changes in the distribution of UGSs can satisfy the needs of all inhabitants and offer equal services to inhabitants from different socioeconomic backgrounds. This study addresses this issue by analyzing dynamic changes in UGS accessibility in 2012, 2016, and 2020 for inhabitants of the central urban area of Fuzhou in China at the community level. The study introduces multiple transportation modes for an accessibility estimation based on a framework using the two-step floating catchment area method and examines the dynamic changes in community deprivation of UGS accessibility using Kernel regularized least squares, a machine learning algorithm. The results demonstrate that spatial disparities of UGS accessibility exist among the multi-transport modes and vary with time. Communities with high accessibility to UGSs by walking are scattered around the urban area; for accessibility by cycling, the high accessibility regions expand and surround the regions with low accessibility in the core urban areas, forming a semi-enclosed spatial pattern. However, the core urban spatial orientation of UGS accessibility by public transit demonstrates a reverse trend to the above two modes. The spatial pattern of UGS accessibility also varies over time, and the growth rate of accessibility slightly declined during the study period. Furthermore, the increase in UGS accessibility tended to slow from 2016–2020 compared with 2012–2016, and the trend toward equality was also erratic. The degree of deprivation for communities first weakened and was then aggravated, corresponding to the slowdown in the growth rate of accessibility, leading to the persistence existence of social inequality. Moreover, significant deprivation mainly exists among less educated people or those using the cycling and integrated travel modes. Although public transport is developing, deprived communities, such as communities with large proportion of older people, have experienced a decline in access to UGSs by public transport. Based on these findings, the study proposes a policy framework for the balanced distribution of UGSs as part of urbanization.

Keywords: urban green spaces, dynamic changes, deprivation, multiple transportation modes, distribution disparity

INTRODUCTION

Urban green spaces (UGSs) primarily comprise urban land with naturally occurring and introduced vegetation. Such areas include lands used for greening within the scope of urban development land and green areas outside urban development land that positively affect urban ecology, landscape, and inhabitants' leisure life (1). UGSs provide a range of ecosystem services, such as beautifying the urban landscape, air purification, noise reduction, and local climate regulation, and contribute to maintaining urban biodiversity (2, 3). Meanwhile, UGSs protect the public health of urban inhabitants and provide a public space for leisure and recreation, which helps inhabitants maintain good social relations and improves their quality of life (4). These factors have great significance for improving inhabitants' well-being and urban sustainability (5, 6). Many studies have confirmed that inhabitants living near UGSs have more opportunities for physical activity, thus reducing the risk of obesity, alleviating mental stress, and improving mental health (7–10). As a critical public service component of any community, UGSs provide social and economic benefits by improving quality of life (11) and enhancing the economic vitality of the surrounding areas (12). The impact of UGSs on inhabitants' well-being is largely determined by accessibility. Combining the above benefits, studying inhabitants' dynamic changes in access to UGSs over time, and understanding the spatial distribution of UGSs and reasons for the social differential in utilizing them could greatly promote social equity.

Reasonable accessibility, which means that many people have access to UGSs services, is a precondition to realizing the value of UGSs (13, 14). However, rapid urbanization poses a large threat to the connection between humans and the natural environment, resulting in a series of conflicts between urban construction land development and the sufficient and sustainable provision of UGSs for inhabitants. This also leads to the problem of certain groups unable to use these UGSs equally, particularly in developing countries (15–17). In China, although the Government has attached great importance to green space and has introduced a series of greening policies to guide sustainable urban development (18), how these will affect the dynamic changes in UGS accessibility remains to be determined. Furthermore, as the planning of public service facilities is directly related to social justice and equal distribution of resources, increasing concern about the spatial equality of UGSs has emerged in developing countries, including in China. Therefore, a comprehensive analysis of UGS accessibility that considers changes in the population and transportation network and a discussion of the socioeconomic process underlying the distribution pattern of UGSs can provide suggestions that ensure more reasonable accessibility in urban planning management.

The greening of cities is an important part of the Construction of Ecological Civilization advocated by the Chinese Government. Additionally, "The Healthy China Action (2019–2030)" report issued by the Healthy China Action Promotion Committee proposes requirements for mass sports in China, which in turn, require UGSs to provide a "healthy public space" service function. "Building a healthy China" has become a mainstream and long-term topic at the national strategic level. As an important venue for sports activities, convenient accessibility and fair access are the fundamental principles for UGS spatial allocation. However, the extant research on the changes in UGS distribution is inadequate, particularly the analysis of whether urban inhabitants have equal access to UGSs. Uneven use of UGSs hinders the suitability and effectiveness of green spaces system planning and affects the sustainable development of the whole city. Additionally, although the importance of the role of UGSs in public health is gradually increasing in most east Asian countries that are rapidly aging (19, 20), most studies on the health benefits of UGSs have been conducted in Euro-American countries (19, 20). Previous research on UGS accessibility for people with different socioeconomic statuses (SES) is insufficient in developing countries like China. Furthermore, the effect of different modes of transportation on UGS accessibility has not been adequately addressed. Therefore, this study provides new insights into the dynamic relationship between accessibility and social deprivation and advances the understanding of unequal UGS provision in developing countries.

LITERATURE REVIEW

Measurements of Accessibility

In this study, accessibility refers to the convenience of travel from an origin to a specified destination (21). UGS accessibility refers to the degree of difficulty faced by inhabitants in overcoming spatial resistance to reach the green space, indicating the proximity between the inhabitants' place of residence and the publicly accessible urban green spaces (22, 23). The reason for applying the concept of accessibility to the evaluation of UGSs is that traditional indicators such as per capita ratio that have commonly been used in the past do not take into account the convenience offered by the services of parks or green spaces to inhabitants (23). However, accessibility is a people-oriented concept that makes up for this deficiency. In recent years, the research on measuring UGS accessibility has received increasing attention (24, 25). Traditional studies mainly measure the road network distance from residential areas to the nearest facilities (24) to reflect or examine accessibility using different means of transportation (26). However, these studies seldom take into account the factors that combine the supply and demand sides. Accessibility depends on the transportation network and travel mode and includes the supply scale of green space, the demand competition of inhabitants, and other factors, which means that there are more methods available for measuring accessibility.

The commonly used methods can be roughly divided into two categories. The first method is based on spatial interaction, mainly represented by the gravity model, and assumes that the spatial interaction decreases with the spatial interval (travel distance or time) between the destination and origin (17). Spatial interaction increases with the increasing demands of the origin or supply capacity and attractivity of the destination (27). The current research is mainly based on spatial interaction to calculate inhabitants' willingness to visit UGSs (28), but this ignores the impacts on the residential population; that is, the potential population burden of UGSs. The second method is based on cumulative opportunity, which is represented by the two-step floating catchment area method [2SFCA (29) and its extension (30, 31)]. The method search for all inhabitants and public service facilities falls within the catchment area successively, ultimately determining the sum of the supply and demand ratio. Compared with the method of spatial interaction, the method based on cumulative opportunity is more practical for the following two reasons. First, the spatial interaction model may exaggerate the accessibility score of areas with poor accessibility. This results in regional differences being ignored and false identification of underserved areas by policymakers. Additionally, the spatial interaction model is determined by analyzing the distance decay effects of specific travel modes, which are difficult to obtain. Although the analysis results of the two-step mobile search method are relatively objective, the extension of the 2SFCA, which is based on multiple travel modes, is seldom applied in the research on green space accessibility. The issue of spatial equality of UGSs has been addressed by a series of studies that have examined traveling to UGSs using a pre-set single (or uniform) transport mode (28, 31, 32) or within a specific distance threshold (29, 31). Other scholars have noted that accessibility should be highly sensitive to different transport modes (33). To date, however, there are limited explanations for the mechanisms involved in the dynamic changes in accessibility by multi-mode transport over time.

Deprivation of Urban Green Spaces

Deprivation can be described by indicators of community socioeconomic disadvantages (e.g., earning power, education, political rights, housing type, and population structure). UGSs are often not distributed equitably, and the unfair spatial distribution is closely related to social injustice (34). A growing body of literature has demonstrated that the spatial distribution of UGSs has been stratified for population segments of different ages, genders, ethnic backgrounds, social statuses, incomes, and other axes. They contend that accessibility varies according to SES. Scholars have also evaluated spatial equality by measuring accessibility (35) and considering the differences in social groups (17). The accessibility heterogeneity between different socioeconomic groups usually reflects social equality, converting the research focus of UGS accessibility from "spatial equality" to "social equality." The majority of empirical research on UGSs has demonstrated the characteristics of the inverse care law, where urban public resource allocation centers on high-income residents. For example, UGSs are characterized by being concentrated in high-income neighborhoods (36–38) and being available to people who own houses (39), mainstream ethnic groups (24, 40), and people of high socioeconomic status (41, 42). This demonstrates a corresponding relationship between the injustice caused by the spatial distribution of UGSs and the social injustice of deprivation, while the inverse care law reflected in the spatial distribution of UGSs indicates deprivation. However, some studies have demonstrated that the correlation between UGS accessibility and SES is insignificant (35, 43, 44), while others have concluded otherwise (45, 46).

In conclusion, the above variance in results is not limited to the different social backgrounds or different temporal intervals of the previous studies. They are also attributable to technical limitations such as the inability of regional units to represent the service areas of the UGSs, aggregation errors caused by the Modifiable Areal Unit Problem (MAUP; the measurement of spatial distributions according to different geographical divisions of a given number of areas induces different results), and limitations caused by distance measurement options (47). Furthermore, for accessibility estimation, if the different transportation modes of inhabitants are neglected, the outcomes are one-sided and unrealistic, which causes misidentification of the deprivation of UGSs for disadvantaged groups. The uncertainty of the research results weakens the evidence base for effective policy interventions to eliminate the deprivation and results in less effective mitigation programs.

The few empirical studies that have focused on community deprivation of urban green spaces in China have mainly been conducted in metropolitan cities like Beijing, Shanghai, and Shenzhen. However, most of these megacity or megacity behemoths have implemented stricter policies for the control of migrants, and the permanent population growth has slowed down, and in some cases, it is negative. With the total amount of green space unchanged, the per capita possession could increase. On the contrary, as the residency restrictions on migrants have been relaxed in provincial capitals and other cities, the process of rapid population agglomeration toward some mid-sized cities is still ongoing. The local governments of most cities also intend to strengthen the construction of urban green space. Under the background of rapid urbanization, whether the behavior of the city government relieves the deprivation of green space needs to be clarified by relevant research. Additionally, while plains dominate the topography of the case city, other complex topography may restrict the space for urban development, and the area of land available for green space construction might be limited.

Finally, the previous studies have adopted relatively static perspectives, and there is no rigorous explanation for selecting time nodes. Nevertheless, it is critical for dynamic research to choose more representative time nodes to test the effectiveness of the local Government's green space planning implementation. In summary, in the research on dynamic change in UGS, we need to shift our focus to non-megacities with complex topography. Meanwhile, we must be particularly cautious in choosing the research time nodes so that the research results can truly reflect the changes in spatial and social equity of UGSs during the process of green space planning.

The Present Study

In this study, the central urban area of Fuzhou (119°E, 26°N) was selected as a representative case with longer and more meaningful research temporal intervals, as this city is set in a valley surrounded by rolling hills, and the available space for urban expansion is limited. Fuzhou was deemed a National Ecological Civilization Pilot Zone, with the highest green space coverage rate nationwide. Fuzhou has been awarded titles such as National Garden City, National Model City for Afforestation, National Ecological City, and National Forest City. Fuzhou's long history and geographical conditions have laid the foundation for the establishment of UGSs. Meanwhile, the local Government also attaches great importance to green space construction.

According to the specific goals for constructing green space proposed by the green spaces system planning of Fuzhou city (2013–2020), the per capita green area for the central urban area was 15 m^2. While Fuzhou's UGS surface per capita is higher than most other cities in China, equitable access to UGSs cannot be captured using the total UGS surface per capita (48).

Additionally, over the past few years, the city has witnessed burgeoning population growth, which has accelerated urban land-use conversion and infrastructure development. Therefore, whether the excellent natural base combined with previous efforts results in an equal supply of green space or requires further adjustments is uncertain and needs to be explored in depth. To provide useful suggestions for urban planning by exploring UGS accessibility in southeast China and its dynamic relationship with social and economic factors, fine-scale demographic datasets at the community level were collected from 2012 to 2020. This timeframe corresponds to Fuzhou city's green spaces system planning (2013–2020) undertaken by the local Government. It is meaningful to analyze the dynamic changes in green space accessibility from the perspective of social equality to lay the foundations for future urban development.

As illustrated in **Figure 1**, Fuzhou is the provincial capital of Fujian province, which is located in China's southeast coastal area, faces Taiwan, and has beautiful landscapes and a pleasant ecological environment. The central urban area of Fuzhou

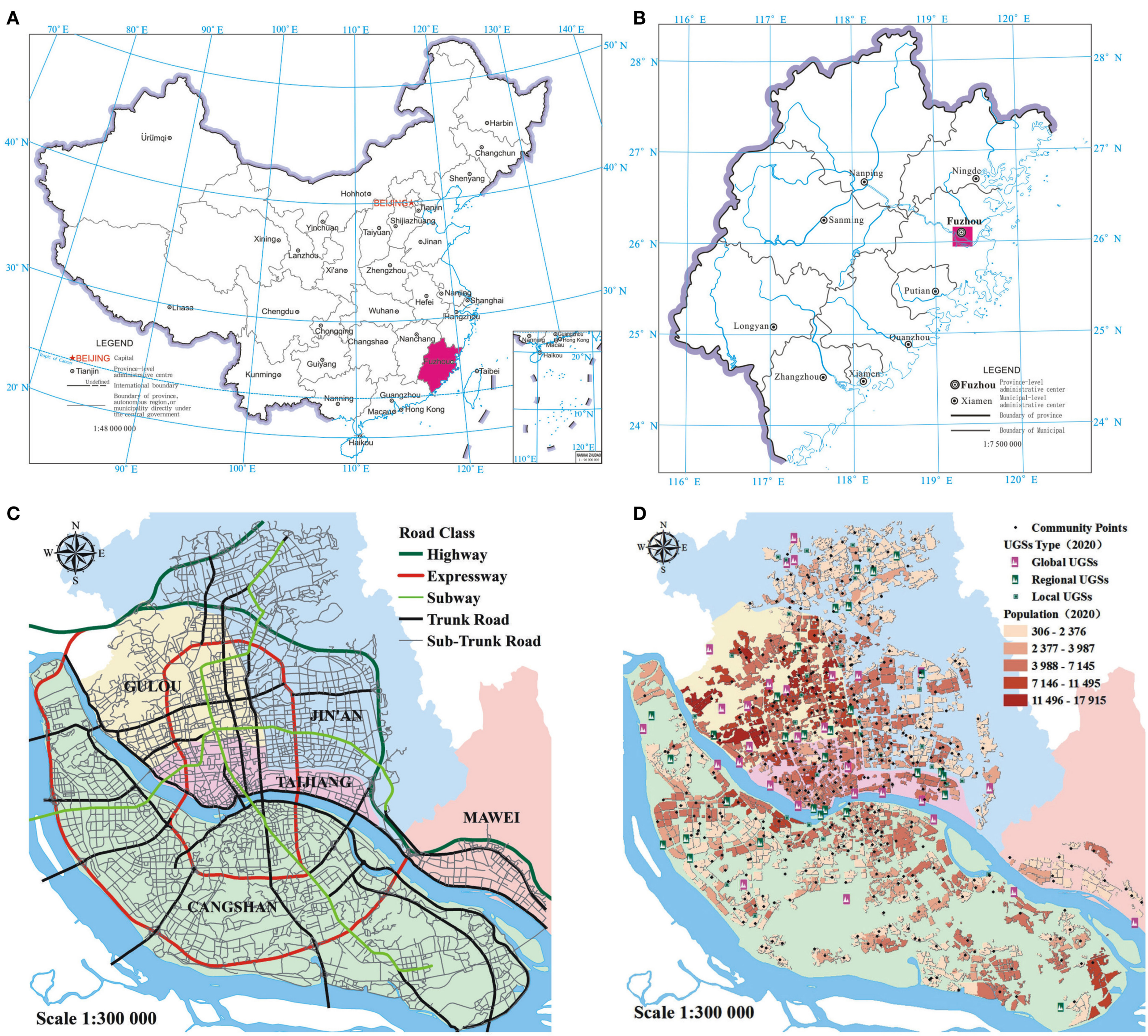


FIGURE 1 | Location of the study area in China and the UGSs, population demands, and transportation systems within it. The collection and division of green spaces for specific years.

TABLE 1 | Data type, data content, and its main application in the study.

Data type	Data content and source	Main application
Remote sensing imagery	Imagery provided by Resources satellite three (ZY-3), acquisition date = March 9, 2013 at a resolution of 0.5 m; Gaofen-2 satellite (GF-2), acquisition date = December 7, 2016 at a resolution of 0.8 m; Gaofen-2 satellite (GF-2) acquisition date = February 2, 2020 at a resolution of 0.8 m	For the collection of UGSs and verification of road network in 2012, 2016, and 2020
Spatial data and attribute data for the UGSs	The data of UGSs origin from Map World-Fujian and the green space system planning of Fuzhou city	For the acquisition of UGSs combined with imagery; As the basis of location, area, and classification for UGSs
Travel survey that assesses purpose of travel to UGSs	Field investigation and questionnaire	To estimate the threshold travel time by multi-mode transport; To check the actual situation of UGSs
Road network and community location	Fujian fundamental geographic information database	For the acquisition and vectorization of road networks and community area in 2012, 2016, and 2020
Demographic properties	The data of population characteristics obtained from the population information management system	As the relevant attribute information for the community

consists of five districts with high transport network density and several UGSs belonging to different categories (**Figure 1**). From 2012 to 2020, the city experienced rapid urbanization, population growth, and infrastructure development. For example, two metro lines were built and implemented successively, and the average transport network density grew by approximately 50% from 2012 to 2020. Based on Fuzhou City's (2011–2020) urban planning, the urban population of Fuzhou central city was expected to be 4.1 million at the end of 2020, increasing by over a million compared with the population in 2012. Although the green space continues to be planned and constructed, there is still no empirical research on whether the increase can keep pace with the increase in the inhabitants' demand and guarantee equal well-being to all inhabitants. Therefore, the specific objectives of this study are as follows: (1) analyze the accessibility to UGSs by multi-mode transport over time; (2) reveal the social inequalities by exploring the dynamic relationship between community deprivation and transport modes in relation to varying accessibility of UGSs; and (3) enrich the current literature on geographic accessibility and provide spatial insights into deprivation to formulate more contextualized and effective plans for policymakers.

DATA AND METHODS

Data and Pre-processing

UGS spatial data were obtained through remote sensing (RS) image interpretation. Using remote sensing image interpretation, combined with Map World-Fujian (the provincial level branch of the national platform for common geospatial information system) in related years and green space system planning, the quantity and location of UGSs were verified and validated through a field investigation. The complete data are listed in **Table 1**.

The base year (2012) of the relevant attribute data, such as the area and classifications of UGSs, were mainly obtained through an actuality investigation of Fuzhou city's green space system planning (2013–2020). Other extensions and newly developed UGSs in 2016 and 2020 were jointly determined from remote sensing (RS) interpretation, together with the green space system planning. The classifications of green spaces that were not included in the planning were mainly determined based on their area. Additionally, considering the rationality of the accessibility analysis results, belt-like open green spaces were divided into several parts according to their multi-entrances. The details of the data collection are illustrated in **Figure 2**, demonstrating that the number of UGSs has been increasing annually and had reached 90 by 2020.

Furthermore, road availability for multi-mode transport was determined by RS imagery, traffic rules, and field investigations. The pre-processing for road networks included the examination and verification of road directions and built or under-construction roads. Road network access and topological relationships were evaluated depending on the actual situation. Roads were divided into different types, such as highways, city circles, and auxiliary roads. According to different travel modes, the speed was set for different road categories according to the corresponding national standards and local reality. As illustrated in **Table 2**, a portion of the values was NULL, meaning that specific roads could not be accessed by the related travel modes. A dataset on the demographic properties at the community level in 2012, 2016, and 2020 was obtained for the deprivation analysis. The principles of objectivity, representativeness, and briefness were then taken into adequate consideration for selecting the indicators. Finally, variables representing four categories (age, education, work experience, and household registration status at the community level) were selected from a series of potential indicators (**Table 3**). These methods serve to make the conclusions more convincing.

Multi-Mode 2SFCA for Spatial Accessibility to the UGSs

The study proposes a multiple transportation mode method called the multi-mode 2SFCA, which is based on the framework of the 2SFCA. The multi-mode method is implemented using the following two steps:

Step 1: For each UGS *j*, search for all populations that fall within different predefined threshold travel times by mode from j, and on that basis, draw different catchment areas. Then, compute the supply-demand ratio V_j within the catchment areas

$$V_j = \frac{S_j}{\sum_{k \in d_{jk}(M_1) \le d_0(M_1)} P_{k,M_1} + \sum_{k \in d_{jk}(M_2) \le d_0(M_2)} P_{k,M_1} + \sum_{k \in d_{jk}(M_3) \le d_0(M_3)} P_{k,M_3}} \quad (1)$$

where $d_{jk}\,(M_n)$ is the travel time by mode M_n between UGS *j* and community *k*; and $d_0(M_n)$ is a predefined threshold travel time from *j* by mode M_n. In this way, several catchment areas by mode can be drawn around UGS *j*. V_j reflects the supply availability of UGS *j* that can be offered to a person who can reach it by different transportation modes.

Step 2: For each population community *i*, search for all UGSs (*j*) that fall within the threshold travel time by mode from *i*. Thus, draw the different catchment areas again. The supply-demand ratios within different catchments are weighted by community population size, and the weighted values are added together to calculate the overall accessibility (A_i) of community *i*.

Thus, the accessibility of a community is dependent on the distribution of UGSs, as well as on its population, road network characteristics, and uneven public transport supply:

$$A_i = \frac{P_{i,M_1} \sum_{j \in d_{ij}(M_1) \le d_0(M_1)} V_j + P_{i,M_2} \sum_{j \in d_{ij}(M_2) \le d_0(M_2)} V_j + P_{i,M_3} \sum_{j \in d_{ij}(M_3) \le d_0(M_3)} V_j}{\sum_{v=1}^{3} P_{i,M_v}} \quad (2)$$

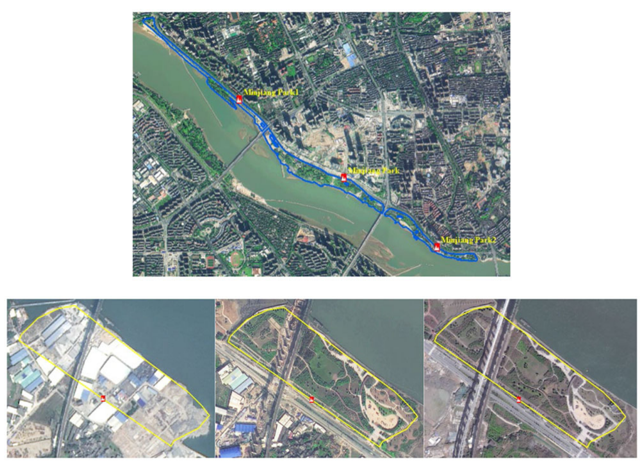
According to the Traffic Analysis Reports for Major Cities in China proposed by AutoNavi and the state information center, Fuzhou has a high green travel willingness index. The cycling travel willingness index in Fuzhou ranks third in China, and the demand for public transport, such as buses and subways, is quite large.

The existing reviews revealed significant spatial heterogeneity in UGS accessibility via walking and public transit. They also confirmed that significant social inequalities widely exist except for the private car mode (17). Furthermore, given the difficulty of obtaining data on the number of cars per family, the study integrates walking, cycling, and public transportation as a multi-mode choice of transport to study UGS accessibility. The model aims to stimulate the status of UGS accessibility. To minimize the bias introduced by MAUP, the multi-temporal analysis was conducted using the minimum possible scale in the given conditions.

During the analysis, it was apparent that selecting a reasonable threshold travel time is the key point for using the multi-mode 2SFCA. To estimate the threshold travel time (by mode) empirically, we used a questionnaire. The results demonstrated that the travel time to UGSs varied according to the travel mode. We could then derive the frequency distribution of trips against travel time (**Figure 3**). It was found that the frequency of trips decreased as travel time increased, and the inflection points for walking, cycling, and public transport were 18, 23, and 33 min, respectively. The 18-min travel time approximates to the cut-off walking trip cost to UGSs that has been used in several previous studies (32, 34). Additionally, the 33-min public transport trip covered approximately 97% of city-level UGSs in the study area, which prevented some sub-districts from having zero values. Therefore, we set the threshold travel time at 18, 23, and 33 min for walking, cycling, and public transport, respectively.

KRLS for Dynamic Changes in Deprivation Associated With UGS Accessibility

A challenge for analyzing dynamic changes in deprivation is that the marginal effects are always heterogeneous across the covariate space that cannot be appropriately handled by generalized linear models (GLMs). Furthermore, GLMs have significant shortcomings as the existence of highly interdependent relationships among the demographic properties of the community does not conform to the inherent assumptions (49). While more flexible methods that do not rely on linear or additive hypotheses have occasionally been proposed, none of these have received widespread acceptance due to their lack of applicability and interpretability (50, 51). Therefore, a growing body of literature addresses social issues using machine learning algorithms, which provide a strong capability to deal with non-linear and interactive data without strict theoretical and parametric assumptions (52, 53). In addition to the advantages mentioned above, Kernel regularized least squares (KRLS) regression provides closed-form estimates for the pointwise partial derivatives that characterize the marginal effects of each independent variable across the covariate space. The method also allows for interpretation and inference in ways similar to that of GLMs (50). Given the above, the study utilizes the KRLS to analyze the dynamic relationship between community deprivation and UGS accessibility. The



2012 2016 2020

FIGURE 2 | The collection and division of green spaces for specific years.

TABLE 2 | Travel costs of different road classifications by multi-mode transport.

Road classification	Highway	Expressway	Trunk road			Sub-trunk road		Subway	
	Highway	City circle	Auxiliary road	Main Street	Minor street	Ramp	Feeder	Internal road	Subway
Public transport	50	40	30	30	30	20	20	20	50
Cycling	-	-	-	15	15	-	15	15	-
Walking	-	-	-	5	5	-	5	5	-

TABLE 3 | Descriptive statistics of the selected socioeconomic variables of the community.

Variables	Explanation	Max	Min	SD	Mean
Older population	Proportion of people aged over 65 years	0.44	0.04	0.07	0.24
Unemployment	Proportion of unemployed people	0.88	0.01	0.15	0.19
Illiteracy	Proportion of illiterate people	0.34	0.04	0.06	0.15
Less educated population	Proportion of people with degree lower than junior middle school	0.95	0.10	0.15	0.46
Floating population	Proportion of floating people	0.89	0	0.20	0.24

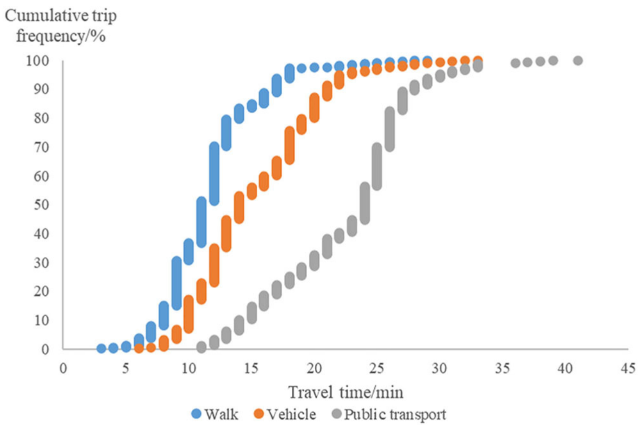


FIGURE 3 | The cumulative trip frequency of UGSs-oriented trips against the travel time by multi-mode transport.

representative variables were selected from a set of potential variables about SES, and they were divided into several categories. The best subset selection was then obtained by going through all the permutations.

RESULTS

The Interpretation of Transport Modes—Varying Accessibility of UGSs Over Time

The central urban area of Fuzhou city has witnessed an overall improvement trend in UGS accessibility from 2012 to 2020 using multi-mode transport (**Figure 4**). The spatial heterogeneity for the UGS accessibility of the specified year indicates great variations among different transport modes. The regions with high accessibility by walking mode are scattered around the urban area. In the cycling mode, the high-accessibility regions are in the western, eastern, and northern periphery areas, and these surround the low-accessibility region in the core urban areas, forming a semi-enclosed spatial pattern. The difference between the high-value regions and their surrounding regions is more pronounced in the north and east, where the major UGSs are located. However, the distribution of high accessibility by public transit mode has a core urban spatial orientation, the complete opposite of the above two modes. The high accessibility by public transit appears as contiguous spatial units in the core urban areas, and the advantages in the accessibility of the periphery by walking mode and cycling mode weaken. The spatial heterogeneity of the integrated travel modes is mostly similar to the cycling mode pattern through which access is limited in the core urban areas. The spatial pattern of UGS accessibility also varies over time by the same mode, and the overall dynamic process leads to a decrease in the area with limited accessibility. For example, the high accessibility by public transport is concentrated around the core urban areas and then expands, particularly to the southeast. The semi-enclosed spatial pattern for cycling tends to weaken gradually, for which the accessibility of the core urban areas continuously improves. Thus, UGS accessibility becomes evenly distributed over time.

A previous study identified the relative role of local contributors, such as population and transport networks, on accessibility changes (29). The present study further measured the dynamic changes in UGS accessibility in response to the evolution of the UGS classification system by multi-mode transport, which has rarely been investigated. As illustrated in **Table 4**, although the accessibility of city-level UGSs by cycling or public transit has declined slightly from 2016 to 2020, which undoubtedly has an adverse effect on the total growth, accessibility has grown overall and for most UGS classifications during the time intervals. While the accessibility for the community-level and district-level UGSs has achieved steady growth, the inhabitants have increasingly easy accessibility to all UGSs classifications by walking.

The detailed dynamic changes in UGS accessibility among communities are presented in **Figure 5** for single (walking, cycling, and public transport) and integrated travel modes. The UGS accessibility data distribution varies greatly with multi-mode transport. Apart from the more concentrated data for walking, the extreme values account for a higher proportion than for other travel modes. During the study period, the data distribution by public transport changed dramatically. Within the boxes, the upper 50% of values by public transport occupied a larger proportion from 2012 to 2016 and then narrowed to approximately equal from 2016 to 2020. Furthermore, by the public transport mode, the box and range of the upper quartile stretch and compress. These processes can be described as a global surge following local enhancement.

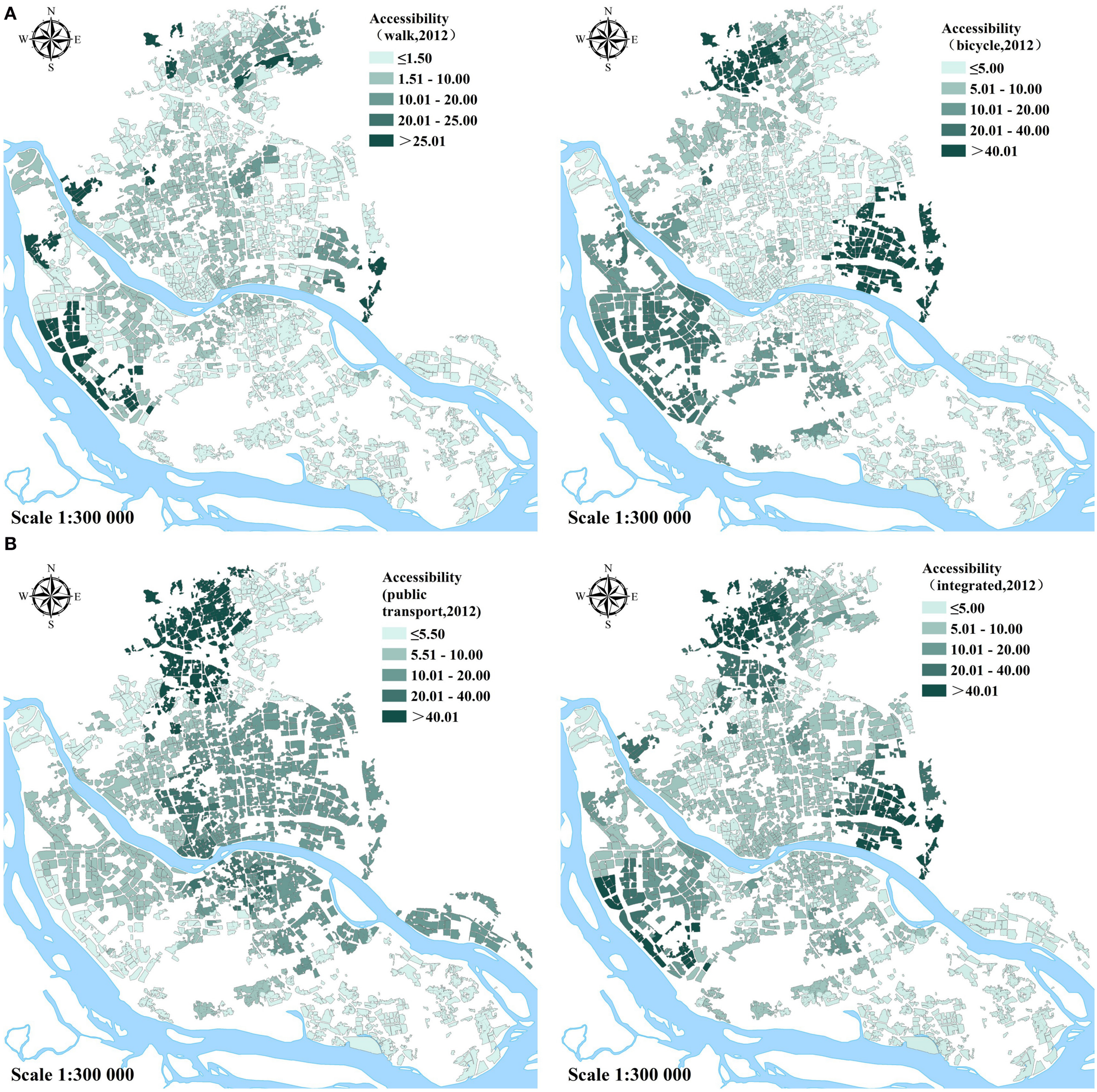


FIGURE 4 | Continued

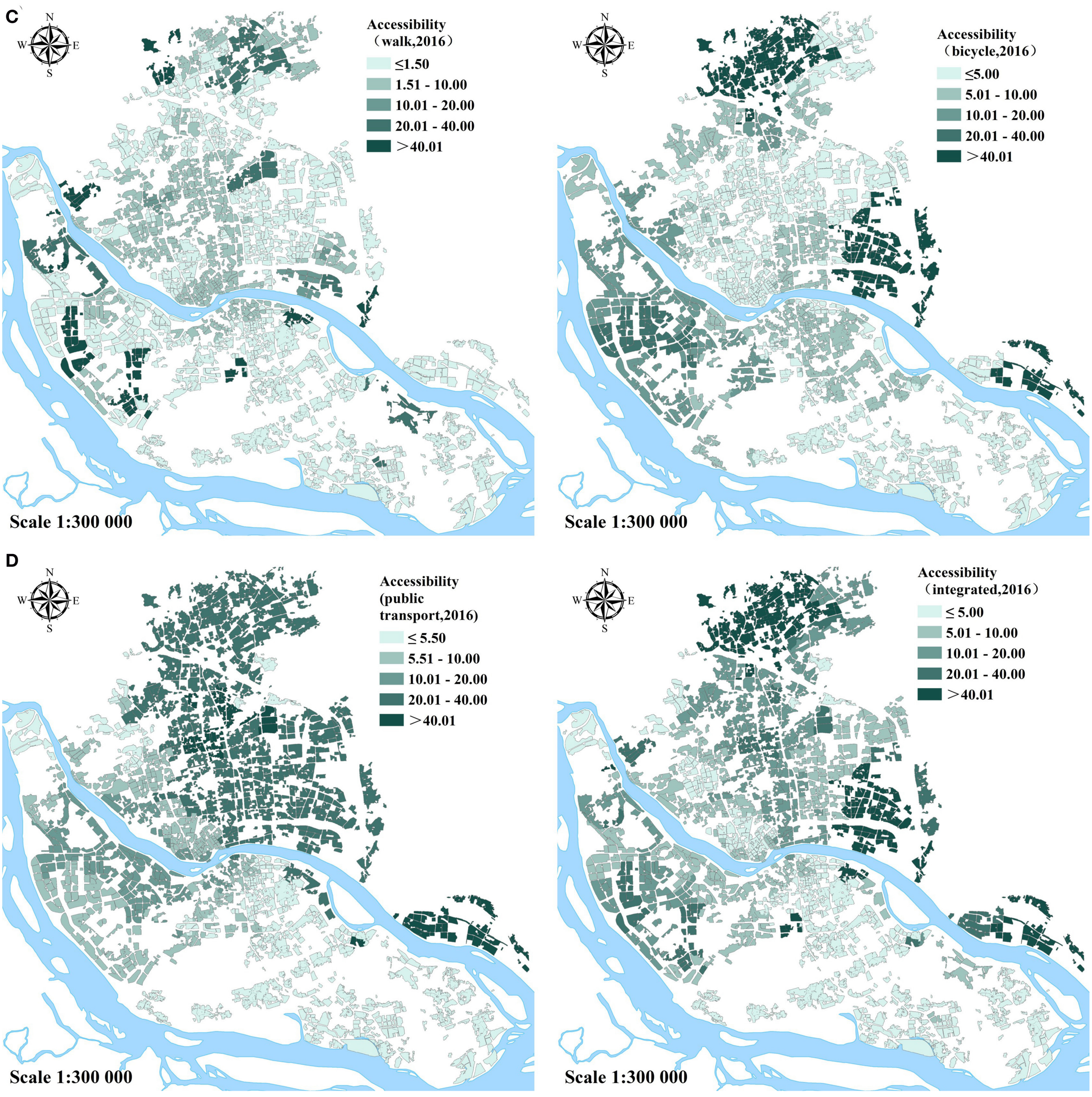


FIGURE 4 | Continued

The Correlation Between UGS Accessibility and Community Deprivation Varies With Multi-Travel Modes Over Time

Tables 5–7 illustrate the relationship between community deprivation and UGS accessibility in 2012, 2016, and 2020. The average column indicates the averages of the marginal effect over the covariate space on the change in UGS accessibility. It cannot reflect the heterogeneous effects of covariates across the units and levels of other covariates for which the relationship between the structural characteristics and UGS accessibility changes in community deprivation had been confirmed. As illustrated in the last three columns, the marginal effects vary by quantile and are listed using P25, P50, and P75. For example, the correlation between less educated people and UGS accessibility changes by walking is always negative. However, the heterogeneity in the pointwise marginal effects is apparent: the average marginal effect

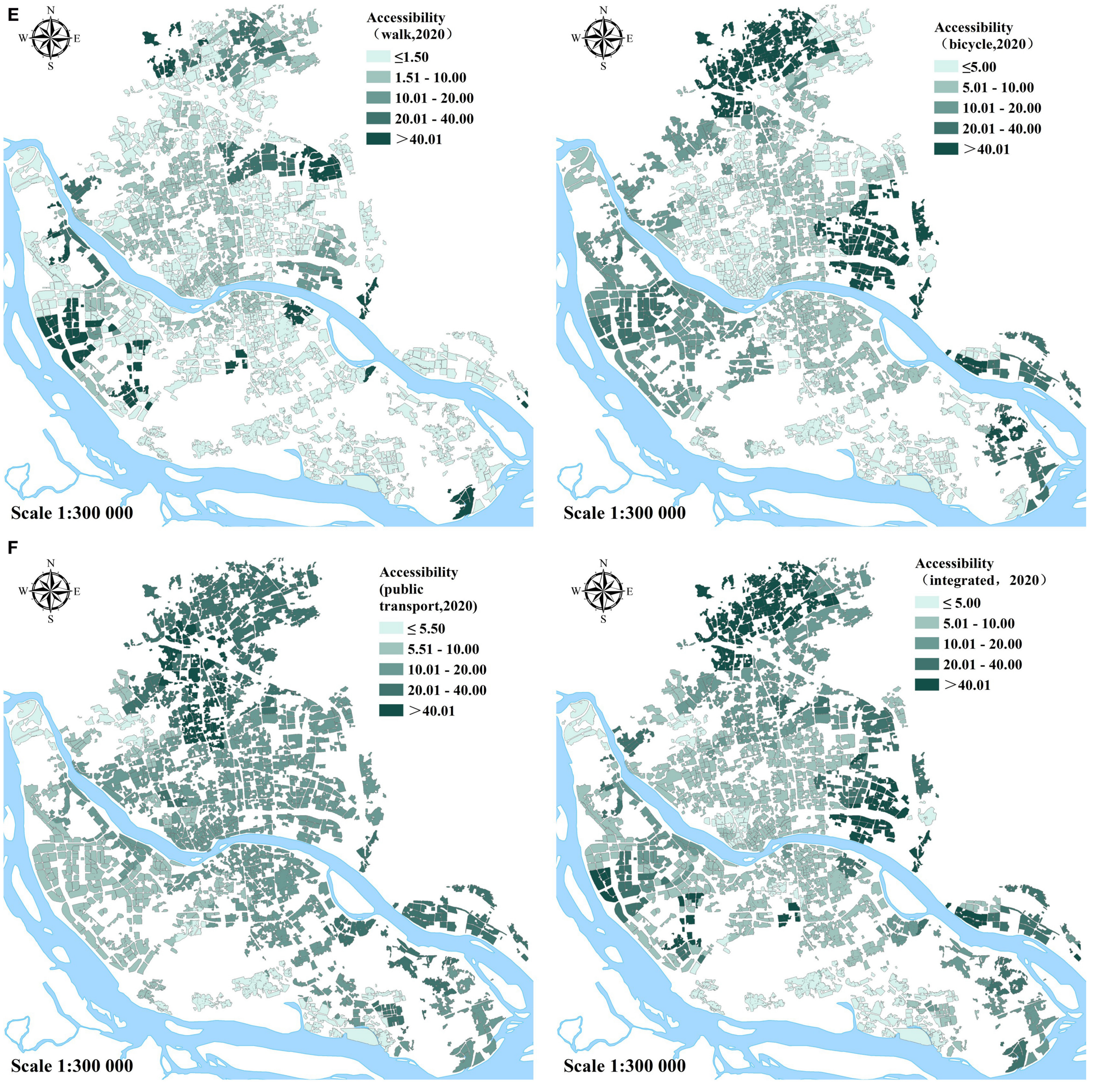


FIGURE 4 | Spatial heterogeneity of varying accessibility of UGSs based on transport modes over time: by the walking, cycling, public transport, and integrated modes in 2012, 2016, and 2020, respectively (unit: square meters per person).

in the fourth row of **Table 5** under the average column is −0.09; in the first quartile, a one-unit increase in the proportion of less-educated people is associated with a 0.17 percentage point decrease in UGS accessibility, while in the third quartile, it is associated with only a 0.03 percentage point decrease in UGS accessibility. The median of the marginal effects is −0.10.

Table 5 demonstrates that community deprivation was evident for some disadvantaged groups in 2012. For example, educationally restricted people (including illiterate and less educated people) negatively correlate with UGS accessibility by multi-mode transport, most notably for less educated people. This indicates that communities with a lower proportion of people with more than nine years of education always have restricted access to UGSs in most travel modes.

As revealed in **Tables 5–7**, the comparative advantages of accessibility for older people seem to gradually weaken or even have disadvantages, except for the walking mode. However, with the aging trend in most communities, the issue mentioned

TABLE 4 | The dynamic changes in the accessibility for different classifications of UGSs during the study period.

	2012				2016				2020			
	Total	**Level-1**	**Level-2**	**Level-3**	**Total**	**Level-1**	**Level-2**	**Level-3**	**Total**	**Level-1**	**Level-2**	**Level-3**
Walking	11.59	0.22	2.00	9.36	12.17	0.26	1.88	10.03	13.13	0.40	2.31	10.43
Cycling	17.99	0.22	2.00	15.76	18.78	0.26	2.23	16.29	18.68	0.40	2.31	15.97
Public transport	17.99	0.22	2.00	15.76	18.78	0.26	2.23	16.29	18.68	0.40	2.31	15.97
Integrated	15.86	0.22	2.00	13.63	16.58	0.26	2.11	14.21	16.83	0.40	2.31	14.12

level-1, level-2, level-3 represent the UGSs of community-level, district-level, and city-level individually.

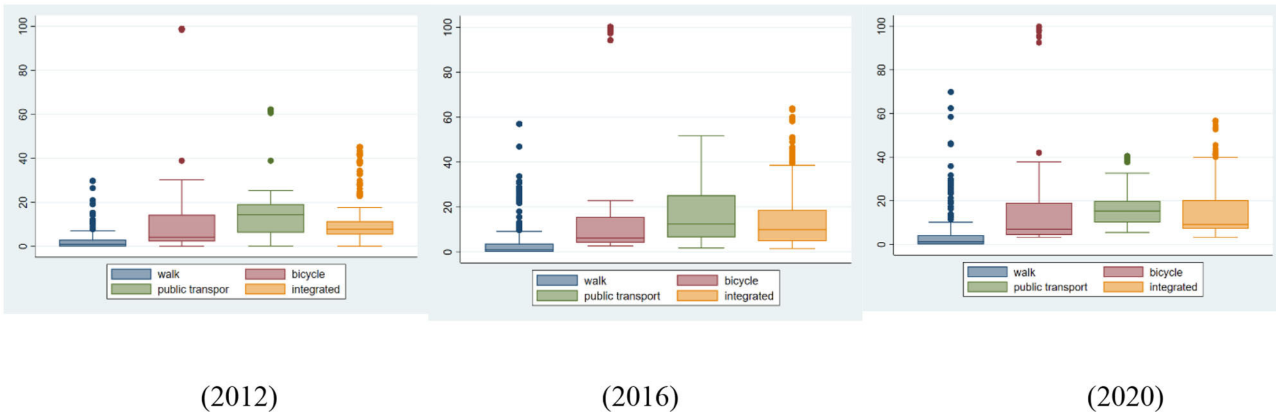


FIGURE 5 | Box plots for the dynamic changes in the accessibility of UGSs by multi-mode transport.

TABLE 5 | Correlation between community deprivation and UGS accessibility by multi-mode transport in 2012.

	Walking				Cycling				Public transport				Integrated			
	Avg.	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**
Aged >60	0.06	−0.03	0.04	0.11	0.08	−0.20	−0.08	0.17	0.21***	0.02	0.21	0.36	0.20***	0.06	0.15	0.29
Unemployed	−0.06	−0.14	−0.06	0.04	−0.07	−0.26	−0.08	0.06	0.21***	−0.06	0.13	0.49	0.06	−0.07	0.03	0.20
Illiterate	−0.08	−0.16	−0.07	−0.01	0.05	−0.06	0.04	0.19	−0.22***	−0.41	−0.26	−0.06	0.02	−0.15	−0.02	0.20
Less educated	−0.09*	−0.17	−0.10	−0.03	−0.25*	−0.36	−0.06	0.06	−0.14**	−0.32	−0.05	0.08	−0.29***	−0.50	−0.29	−0.02
Migrants	−0.05	−0.14	−0.06	0.03	−0.06	−0.14	−0.03	0.07	−0.05	−0.20	−0.04	0.12	−0.06	−0.15	−0.02	0.08

$^*p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$.

above is more serious than what was observed. Educationally restricted communities are moving toward better outcomes in 2016 compared with 2012. However, the accessibility of communities with more aged people is deteriorating, particularly by public transport. In 2020, more disadvantaged groups, including unemployed, illiterate, less educated, and migrant community members, presented negative correlations with UGS accessibility, even though some were non-significant.

DISCUSSION AND CONCLUSIONS

Understanding the Existing and Improving Spatial Inequality of UGS Accessibility That Varies With Multi-Travel Modes Over Time

Overall, UGS accessibility continues to improve, while the region with restricted accessibility has gradually decreased. Fuzhou inhabitants have more opportunities to visit community-level and district-level UGSs, regardless of their chosen travel modes. The spatial distribution of UGSs is optimized through the expansion and spatial rearrangement of green spaces. In particular, inhabitants of the southeastern region, which is also along the city's development corridor, have easier access to UGSs due to the newly built green space in this area. Although the central urban area population has rapidly increased, the increased traffic network density and layout optimization of UGSs allow convenient travel to UGSs. As large-scale UGSs are primarily distributed in the urban periphery, the core urban areas have relatively poor accessibility by walking or cycling. However, core urban areas are always intensive bus route zones, making it very convenient for people to reach UGSs by public transport, particularly with the continuous expansion of Fuzhou subway lines.

TABLE 6 | Correlation between community deprivation and UGS accessibility by multi-mode transport in 2016.

	Walking				Cycling				Public transport				Integrated			
	Avg.	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**
Aged >60	0.15*	0.08	0.13	0.17	0.02	−0.02	0.01	0.06	−0.11*	−0.23	−0.10	0.01	−0.09	−0.16	−0.07	−0.01
Unemployed	−0.04	−0.06	−0.03	−0.01	0.08*	0.02	0.07	0.14	0.08	−0.06	0.06	0.19	0.08	0.01	0.09	0.16
illiterate	0.03	−0.01	0.02	0.09	0.08*	0.04	0.09	0.12	0.23***	0.07	0.20	0.44	0.09	−0.01	0.09	0.17
Less educated	0.01	−0.05	−0.01	0.04	0.06	−0.02	0.05	0.13	−0.06	−0.15	−0.03	0.07	−0.09	−0.17	−0.10	−0.02
Migrants	0.04	0.01	0.06	0.11	0.03	−0.01	0.04	0.07	0.14**	0.01	0.13	0.27	0.09*	−0.01	0.07	0.16

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

TABLE 7 | Correlation between community deprivation and UGS accessibility by multi-mode transport in 2020.

	Walking				Cycling				Public transport				Integrated			
	Avg.	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**	**Avg.**	**P25**	**P50**	**P75**
Aged >60	0.11*	−0.01	0.08	0.22	−0.07	−0.25	−0.07	0.11	−0.09	−0.11	0.08	0.19	−0.13*	−0.27	−0.07	0.04
Unemployed	0.01	−0.08	0.01	0.12	−0.15**	−0.34	−0.16	0.04	−0.13	−0.35	−0.11	0.10	−0.23***	−0.50	−0.21	0.01
Illiteracy	−0.05	−0.22	−0.08	0.15	−0.20***	−0.39	−0.12	0.06	−0.05	−0.33	−0.05	0.11	−0.28***	−0.54	−0.14	0.02
Less educated	−0.03	−0.24	−0.03	0.18	−0.24***	−0.66	−0.06	0.19	−0.10	−0.48	−0.10	0.19	−0.27***	−0.53	−0.22	−0.07
Migrants	−0.14*	−0.39	−0.12	0.03	−0.08	−0.25	−0.02	0.17	0.10	−0.12	0.08	0.27	−0.01	−0.17	0.04	0.19

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

The Healthy China Action (2019–2030) report advocates a healthy lifestyle, insisting on low-carbon travel; prioritizing walking, cycling, or public transportation; and advocating more shared transportation. However, the multi-mode practice continues to lag in UGS accessibility research. In this study, the catchment area for walking is approximately 15 min on the physical exercise scale mentioned in the action program. Nonetheless, the results presented in **Figure 1** illustrate that accessibility by walking is generally inadequate. The spatial heterogeneity by cycling mode is more significant, indicating serious spatial inequality. By public transport mode, the region with the best access to UGSs tends to be consistent with the region with high levels of public transport density, which may be unfavorable to disadvantaged groups who live on the urban periphery where the public transport system needs to be further developed. Given that the spatial patterns of UGS accessibility vary with multi-mode transport, the promotion of spatial equality should not be confined to the optimization of allocation of UGSs.

Additionally, to date, more than half of the communities continue to have a limited per capita area of UGSs within the catchment, which is less than the required area for a National Ecological Garden City (beyond 12 per capita area). Confined by the pressure of rapid population growth, UGS accessibility tended to be stable in the last 4 years (2016–2020) after the definite increase, which was mainly concentrated in the previous 4 years (2012–2016). Due to the large scale of the green spaces distributed in the periphery of the urban areas, the ideal accessibility to city-level UGSs depends on cycling or public transport. In contrast, as community-level UGSs are mostly located in the core urban areas with high population densities, the accessibility and potential to improve are limited.

Interpretation of Social Equality From the Perspective of UGS Accessibility

The limited access to UGSs for disadvantaged groups at the community level reflects the existence of community deprivation. The specific disadvantaged groups have different accessibility by multi-mode transport, and this access also changes with time. Overall, significant deprivation mainly exists for less educated people or those using the cycling and integrated travel modes. Less-educated people tend to live in communities characterized by lower coverage of green spaces and fragmented and narrow lanes (54). This explains the community deprivation in UGS accessibility in the cycling travel mode, which further affects deprivation in the integrated travel mode.

The dynamic changes in accessibility cannot be captured completely if only two time nodes are selected for comparison (the origin and destination). However, even with three or more time nodes, the results could be insufficiently convincing if the time intervals are short. Therefore, this study selected three representative time nodes for which the time interval was sufficiently long to observe changes. **Tables 8**, **9** illustrate the relationships between community deprivation changes and dynamic changes in UGS accessibility between the last 4 years (2016–2020) and the previous 4 years (2012–2016). For a community with a growing proportion of disadvantaged groups, such as unemployed people and migrants, UGS accessibility by the most modes of transport continues to grow from 2012 to 2016, even though not all modes were significant. However,

TABLE 8 | Correlation between community deprivation changes and the dynamic changes in the UGS accessibility from 2012 to 2016.

	Walking				Cycling				Public transport				Integrated			
	Avg.	P25	P50	P75	Avg.	P25	P50	P75	Avg.	P25	P50	P75	Avg.	P25	P50	P75
Aged > 60	0.17***	0.09	0.18	0.25	0.02	−0.05	0.03	0.09	−0.17**	−0.31	−0.16	−0.02	−0.09*	−0.14	−0.09	−0.03
Unemployed	−0.07	−0.11	−0.07	−0.03	0.05	−0.09	0.06	0.20	0.06	−0.07	0.05	0.20	0.06	0.01	0.06	0.12
Illiterate	−0.01	−0.05	−0.01	0.04	0.08	0.01	0.10	0.17	−0.07	−0.22	−0.03	0.12	−0.04	−0.10	−0.03	0.03
Less educated	−0.07	−0.14	−0.04	0.01	0.04	−0.05	0.02	0.09	−0.02	−0.18	0.01	0.17	−0.06	−0.13	−0.05	0.01
Migrants	−0.03	−0.09	−0.04	0.02	0.01	−0.05	0.02	0.07	0.22***	0.01	0.23	0.48	0.08*	0.02	0.10	0.16

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

TABLE 9 | Correlation between community deprivation changes and the dynamic changes in the UGS accessibility from 2016 to 2020.

	Walking				Cycling				Public transport				Integrated			
	Avg.	P25	P50	P75	Avg.	P25	P50	P75	Avg.	P25	P50	P75	Avg.	P25	P50	P75
Aged >60	0.04	−0.01	0.06	0.11	−0.04	−0.08	−0.04	0.01	0.02	−0.09	0.04	0.13	0.03	−0.08	0.03	0.15
Unemployed	0.09*	0.04	0.08	0.13	−0.05	−0.08	−0.04	−0.01	0.03	−0.10	0.04	0.17	0.02	−0.05	0	0.10
Illiterate	0.03	−0.03	0.02	0.08	−0.02	−0.05	−0.02	0.02	−0.07	−0.19	−0.07	0.06	−0.11*	−0.18	−0.11	−0.04
Less educated	−0.05	−0.07	−0.02	0.02	−0.04	−0.07	−0.04	0.01	−0.08	−0.24	−0.08	0.07	−0.08	−0.17	−0.08	0.01
migrants	0.02	−0.04	0.03	0.10	−0.05	−0. 08	−0.06	−0.03	0.06	−0.11	0.05	0.24	0.06	−0.02	0.06	0.15

$p < 0.05$.

there is scarcely any change in equity from 2016 to 2020 except for the accessibility by walking mode for unemployed people, but 2016 appears to have been an important turning point in community deprivation of UGSs. For example, the dynamic correlation between illiteracy and UGS accessibility showed more serious significant negative before and after 2016, which means that changes in the accessibility dynamic failed to keep up with the changes in illiteracy. Combined with the accessibility changes in relation to community deprivation in 2012, 2016, and 2020, the correlation coefficient changed from partially positive to totally positive and then totally negative, indicating that UGS accessibility may not be sufficient to make up for the inequality of illiteracy. The access to UGSs among inhabitants with different SES is relatively equitable in 2016.

In other words, within the study period, equality of access to UGSs tended to first increase and then decrease. The social inequality from the perspective of UGS accessibility is similar to the green gentrification that has garnered widespread concern, particularly in Western countries (48, 55). The issue is closely related to the marginalization of disadvantaged groups and residential segregation, but it is frequently ignored in China (56). The re-emergence of inequality serves as a reminder to the Government that current green planning should be revised to prevent the realization of the inverse care law. It is noteworthy that the significant negative correlation between disadvantaged groups and UGS accessibility disappeared along with the rapid development of public transport, which could be seen as manifesting the trend toward a more equitable society. It can be said that the opening and operation of Fuzhou Subway Lines increases transportation convenience for disadvantaged groups.

In conclusion, this study revealed the periodic characteristics of community deprivation, which has seldom been discussed to date. Although rare studies on the same topic present different conclusions (20, 29), it has been difficult to provide a broad overview of the development of deprivation and even more difficult to determine when UGS accessibility becomes more favorable for disadvantaged groups. The limitations in the timelines create difficulties for policymakers in terms of formulating effective and timely responses. With the aid of long-time-series data, this study found that the degree of community deprivation is alleviated at the beginning but becomes more serious later. This change demonstrates the importance of studying temporal and spatial variations in demand based on dynamic monitoring of the population. Furthermore, the varying accessibility of UGSs by multi-mode transport also suggests that planners should focus on the connectivity between UGSs and communities and draws a blueprint that is suitable for a multi-mode choice of transport. Finally, the social inequalities of UGS accessibility are explained by their historical and social context, although their associations are not always linear and the mechanism is complex (29, 57). Therefore, the inequalities are difficult to eliminate in the short term, but it is possible to adopt more flexible solutions.

Policy Implications

This study identified that the Government should formulate equalizing policies to improve the accessibility of the disadvantaged groups, even though the growth rate of spatial accessibility did not stall or even reversed during the study period. Similar to the importance of balancing the relationship between urban development and social justice, community deprivation in urban green space access is also an urgent problem to be solved in current urban development. Sufficient provision and dynamic spatial optimization of public green spaces are essential to relieve the deprivation of disadvantaged groups. However, the work should not be limited to UGS planning. Previous studies have only provided limited advice rather than a well-established policy framework.

In the process, identifying the deprived communities with limited UGS accessibility is the prerequisite to resolving these issues. In the beginning, policymakers regularly analyzed the demographic changes through population dynamic monitoring. Recently, ubiquitous big data have been widely used in social science research, and social network applications that have check-in options, such as "microblogs" or Twitter, provide researchers with location-based data for studying user behavior when visiting UGSs. Nevertheless, as reflected in the user preferences on social networking, these social network applications are seldom used by disadvantaged groups. This means that many users who belong to a disadvantaged group or those without mobile phones are not included in the research. Big data could be used to supplement traditional sampling statistics to detect regions with poor accessibility. Some prior studies have demonstrated that high-SES groups have better access to public green spaces, partly owing to their greater ability to choose residences with high-quality living environments and participate in planning decisions relevant to their benefits (58). More efforts should be made to provide sufficient green spaces for those communities where disadvantaged groups are rapidly increasing. Ensuring green coverage must be made mandatory for areas with low-cost housing, including affordable and low-rent housing.

Additionally, governments and relevant departments should optimize the road network structure during urban construction. By targeting varying degrees of deprivation through multi-mode transport,they should promote planning and design principles through the "Narrow Roadways, High Density Network" to improve accessibility by public transport and strengthen the construction of cycling and pedestrian lane systems. Furthermore, shuttle busses that connect large-scale UGSs and deprived communities should be incorporated into the planning. The free bus transfer to large-scale UGSs based on existing subways can also be considered, particularly for disadvantaged groups.

Finally, a management system for differentiation and diversification of supply and the trade-off and compensation for UGSs needs to be established. Due to the heterogeneity of urban space and the inhabitants' characteristics, more flexible greening strategies are recommended to create better green space access and improve the inhabitants' daily recreation service experience. For example, for the limited accessibility of community-level UGSs in core urban areas, vertical greening, parkways, and greenways should be added to improve the diversity index and strengthen landscape connectivity (59), thus building a solid foundation for the 15-min physical exercise scale. As the urban periphery always has larger construction space, complete park systems should be established to meet residents' basic requirements. Additionally, the quality and service level of existing UGSs should be strengthened in both core urban areas or the urban periphery, and the diversified functions of UGSs should meet the needs of different groups, particularly older people in the context of an aging society. In public land management, the Government should avoid privatization or quasi-privatization of UGSs due to excessive concentration in high-SES residences. The additional value should be used as a special fund to invest in the construction of UGSs in underserved areas. In practice, policymakers should provide adequate and high-quality UGSs based on the principle of convenience and equality and according to the above-mentioned policy framework. In addition to building a foundation for the "Healthy China Initiative" by offering a convenient space for physical exercise, the UGSs around urban inhabitants should also be used to encourage the sharing of UGSs among all urban inhabitants.

DATA AVAILABILITY STATEMENT

The datasets for this article are not publicly available because of the institutional copyright issues. Requests to access the datasets should be directed to Shunqi Cheng, skylers@vip.qq.com.

AUTHOR CONTRIBUTIONS

All authors made a substantial, direct and intellectual contribution to the work and approved it for publication.

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