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Urban green spaces and human health

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Urban green spaces and human health

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Editorial: Urban green spaces and human health

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Editorial on the Research Topic
Urban green spaces and human health

An essential component of fostering sustainable and regenerative urban development lies in elevating collective wellbeing standards (1, 2). The United Nations officially adopted the 2030 Agenda for Sustainable Development in 2015, outlining 17 Sustainable Development Goals (SDGs) aimed at eradicating poverty, safeguarding the environment, and enhancing the quality of life for all individuals globally by 2030. Urban Green Spaces (UGSs) play a pivotal role in influencing living conditions and public health, directly contributing to several SDGs such as promoting good health and wellbeing (SDG 3), ensuring access to clean water and sanitation (SDG 6), fostering industry, innovation, and infrastructure (SDG 9), and advancing sustainable cities and communities (SDG 11).

The principle of One Health assumes paramount significance by acknowledging the intricate interplay among humans, animals, and the environment as a critical determinant of public health and wellbeing (3). This recognition underscores the necessity for interdisciplinary collaborations to cultivate a comprehensive understanding and implement effective measures against public health challenges (4). However, there are certain drawbacks to the "One Health" strategy. The focus primarily on zoonotic illnesses may inadvertently obscure other environmental health concerns, such as pollution and non-communicable diseases (5). Moreover, there is a chance that this concept may unduly emphasize the features of biological health, thereby ignoring the social and cultural dimensions that have a significant impact on wellbeing. However, the "Eco-Health" approach provides a more comprehensive understanding of health, considering environmental, social, and economic factors that affect health outcomes (6). This strategy emphasizes how critical it is to involve and engage the community in the identification and resolution of health issues (7).

Research has consistently demonstrated the manifold benefits of UGSs on the mental, physical, and social wellbeing of residents (8). Various studies have established correlations between green spaces (e.g., quality, spatial distribution, biodiversity, proximity to residential areas) and health outcomes, encompassing birth weight, adult excessive body weight and obesity, mental and cardiovascular health, and overall mortality rates (9, 10).

These findings underscore the indispensable role of green spaces in enhancing the daily lives of urban dwellers. Despite the wealth of evidence showcasing the interconnectedness of human health and UGSs, there remains a notable research gap in this domain.

The Research Topic, "*Urban green spaces and human health*" featured in the "Environmental Health and Exposome" section of Frontiers in Public Health, aims to comprehensively explore the impact of UGSs on human health. The focus is broad yet specific, encompassing various key areas including (a) UGSs for enhancing public health; (b) Links between UGSs and disease; (c) Influence of UGS quality on mental health; (d) Promotion of sustainable and regenerative urban development through strategic UGS planning; (e) Case studies illustrating the efficacy of greenspace interventions in fostering healthy communities and cities; (f) Examination of the relationship between UGSs and marginalized communities; (g) Utilization of big data mining techniques to enhance the quality of green spaces; (h) Qualitative approaches to understanding the effects of UGSs on human health; (i) Identification of challenges and opportunities associated with the intersection of UGSs and public health; (j) Evaluation of urban living conditions for older adults in the 21st century; and (k) Cross-country disparities in healthy aging within urban settings.

Under this Reaearch Topic, 18 articles have been successfully published with relevant findings contributing to the advancement of research on the impact of UGSs on human health. Deng et al. conducted a meta-analysis on the role of greenways in promoting physical activity, emphasizing the need to recognize greenways as an effective public health intervention. Cao et al.'s study investigated the impact of different environmental conditions on public physiological and psychological health in UGSs, highlighting the significant influence of weather on the restorative potential of these spaces. Li H. et al. delved into the correlation between green recreational activities, residential green spaces, and mental health, reinforcing established "green space-health" frameworks and underscoring the importance of leisure physical activity in boosting mental wellbeing. Zheng et al. laid the groundwork for comprehending residents' spatial experiences and behavioral requirements, conducting a scientific evaluation of UGS quality, and optimizing the structure of community green spaces. Li Q. et al. shed light on the substantial influence of UGSs on the wellbeing of middle-aged and older adults. Zhang T. et al. scrutinized the perceptions of health risks associated with hot weather and the cooling benefits of UGSs, stressing the role of green spaces and water in alleviating urban heat threats and residents' health risk perceptions. Guo et al. identified the essential landscape elements required for hospital rehabilitation spaces through an empirical study of 10 small hospitals. Zhang C. et al.'s research focused on the urban park system for public health, advocating for the optimal development strategy of urban parks at both macro and micro levels to promote sustainable urban public health. Kolster et al. conducted a controlled trial on guided nature walks or group exercises for health promotion in primary care, demonstrating the benefits of nature-based interventions, even in green surroundings, for improving health. Mohr-Stockinger et al.'s study aimed to optimize biodiversity-friendly residential greening to promote health. They highlighted that neighbors are already highly motivated to actively participate in creating locally adapted solutions and taking responsibility for optimizing residential green spaces for health promotion. Fu et al. explored the constraints of community greenways for physical activity using a structural equation model. Their findings provide insights for enhancing people's willingness to utilize greenways for physical activity and offer a theoretical basis for the healthy design and transformation of community greenway spaces. Yang et al. focused on evaluating the quality of life and spatial correlations in impoverished areas of Guizhou Province. They found that while the overall quality of life in all impoverished districts and counties of Guizhou Province has improved, significant disparities in quality of life between the eastern and western regions of the province persist. Xia studied the impact of green spaces on residents' wellbeing. They emphasized that only through an understanding of the relationship between cultural heritage and green development can a virtuous cycle of development be created, thereby promoting the continuous development of a unique and historically significant urban area. Lak et al. examined the impact of older adult-friendly public open spaces in urban impoverished communities on the health of older adults. They highlighted that the personal aspect, socio-demographic status, place preferences, and environmental processes collectively influence the health of older adults. Rose and Riley suggested that key concepts of the five ways to wellbeing can serve as a framework for zoos to engage more effectively with their human audiences. Li J. et al. investigated tourists' perceptions of historic districts, landscape perception, and place attachment. They found that landscape perception significantly influences perceived restoration, with indirect effects through place dependence and identity, as well as a direct impact of landscape perception. Yan et al. studied the psychological health recovery of older adult individuals in parks during different seasons. In winter, perceived environment assessment was not a direct antecedent of restorative effects, with moderate and vigorous physical activity feedback serving as important mediating factors. In seasons other than winter, low physical activity feedback played crucial mediating roles.

Future research in the field of *Urban green spaces and human health* should focus on exploring the differential health benefits of UGSs across various population groups, considering factors such as age, socioeconomic status, and cultural backgrounds. Additionally, there should be a growing emphasis on how urban planning and design can maximize the positive impact of green spaces on mental health, as well as strategies to Protect and promote the sustainability of green spaces in urban development, ensuring better health and wellbeing for future urban residents.

Thank all authors who contributed to this research theme, and we invite readers to explore the excellent articles in this compilation.

Author contributions

YL: Conceptualization, Funding acquisition, Writing – original draft, Writing – review & editing. HL: Funding acquisition, Writing – review & editing. DV: Funding acquisition, Writing – review &

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Quality of life assessment and its spatial correlation in impoverished districts and counties: A case study of Guizhou Province

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China's rapid urbanization has greatly boosted the quality of life of its traditionally impoverished regions. Research into the spatial distribution characteristics, evolution and spatial correlation of the quality of life in impoverished regions can help illuminate the experience of successful development and construct a knowledge base for authorities to devise development strategies. This study focuses its attention on the historically impoverished districts and counties (which are designated as parallel administrative units in China) of Guizhou Province in southwestern China. Extensively citing official statistics on districts and counties released by China's National Bureau of Statistics and local governments, it assesses the quality of life of those places in the 3 years of 2000, 2010, and 2020 from the four dimensions of economy, society, culture, and environment. The aim is to illustrate the distribution characteristics and the evolution of quality of life in Guizhou's historically impoverished districts and counties. In order to understand the characteristics of spatial clustering as well as the patterns of evolution of the quality of life of Guizhou's impoverished districts and counties, the study incorporates spatial autocorrelation analysis into a spatio-temporal analysis of local quality of life. It could presumably help enrich the knowledge base that local authorities draw on to formulate development strategies that are scientific and adapted to local conditions. The study found that while the overall quality of life in all the impoverished districts and counties of Guizhou Province has improved, large gaps in quality of life between eastern and western regions of the province persisted. In addition, the driving force behind the evolution in the overall quality of life of those places changed with time, as did the characteristics of the spatial aggregation in quality of life.

KEYWORDS

quality of life assessment, GIS, spatial correlation, impoverished counties, Guizhou Province

1. Introduction

While often casually used to describe how good life is, the concept of quality of life in technical and scholarly contexts often covers a wide range of aspects. Its definitions are numerous and vastly different (1), but improving the quality of life is always the desired outcome of urban development. Defining quality of life must be based on specific contexts, so as to ensure the

coherence between the definition of the concept and the execution of the research (2). Among existing quality of life (QoL) research projects, most adopt the WHO's definition of the concept, which views quality of life as "an individual's perception of their position in life in the context of the culture and value systems in which they live and in relation to their goals, expectations, standards and concerns" (3). It is generally believed that quality of life is a comprehensive measurement of the physical, mental, social well-being of an individual or of a group. Notably, a large number of studies have demonstrated that the natural environment in which people live is of great importance to their physical and mental health (4). Their financial status also has a crucial impact on their physical, mental and social existence (5). In addition, cultural activities and cultural atmosphere also play a role in promoting people's quality of life (6). Taking all relevant factors into consideration, this study defines quality of life as the sense of satisfaction felt by the individual or the group from their physical well-being and economic, cultural, social and environmental states. It approaches QoL assessment mainly from the angle of urban–rural development.

Research on quality of life has always been considered of great referential value for decision-making, particularly when it takes sustainable development into consideration (7, 8). QoL assessment has been widely used in urban research. It can yield valuable information pertaining to human well-being, urban environmental quality, etc., and influence social progress by shaping relevant policies (9). It can also help elucidate the development experience of a specific places and facilitate the understanding of interregional differences and interactions (10). In addition, by investigating the specific dimensions constituting the overall QoL, urban QoL assessment can also shed light on factors driving the evolution of quality of life (11).

Many scholars have discussed the dimensions of urban QoL. Such discussions are broadly oriented toward three perspectives—personal development, urban development, and a comprehensive perspective combining the two.

An example focusing on the first perspective is that of Robert, who defines quality of life as a combination of the individual's physical health and mental health, both indispensable to personal development, satisfaction, happiness, and well-being (8). Shafer et al. propose that urban QoL encompasses the four dimensions of mobility, accessibility, conviviality and sustainability (12). Smith et al. dissect urban QoL by considering six aspects—livability, diversity, personal freedom, character, mobility and connection (13). Broadly speaking, urban QoL researches emphasizing personal development come mainly from medical science or social sciences and they tend to pay special attention to the quality of life of disadvantaged groups (14).

Adopting the perspective of urban development, Marans in his urban QoL research believes that urban QoL is a composite concept consisting of multiple dimensions such as society, economy, culture, politics, environment and psychology, and that it is generally used to describe people's living conditions (15). Morais et al. divide urban QoL into nine dimensions, namely society, economy, environment, population, public participation, education and training, culture and entertainment, information society, transportation and tourism (16). Węziak-Białowolska argues that urban QoL is constituted by social, economic, institutional, environmental, and physical factors (17).

Urban QoL researches considering both personal development and urban development include that of ANA et al., which highlights the psychological dimension in urban QoL assessment, integrates it into the perspective of urban development, and proposes five dimensions to be considered in urban QoL assessment—psychological, social, economic, political, physical, environmental and mobility-oriented (18). Feneri et al. highlight the subjective feelings of individuals in QoL assessment, and combining them with urban development, propose six broad considerations in urban QoL assessment - environment, infrastructure, safety, health, transportation and others (19).

It is worth noting that, as a composite and interactive system, cities have both the character of a human society and that of a natural ecology. The former is reflected in the activities in and models of economy, culture, and social security, etc.; the latter is based on healthy ecological processes and complete ecosystem services (20). An analytical perspective factoring in both human society and natural ecology can help promote a more thorough understanding of an urban QoL guided by the idea of sustainability (21). Based on a survey conducted in 51 European cities, the research of Vincenzo et al. investigates the impact of green space on the quality of life and points out that urban green space can significantly boost the quality of life (22). In human society, culture often provides the core brand value of a city. It runs through every segment of the city's operation. The culture of a city is increasingly functioning as a catalyst for the fusion of quality-of-life improvement and urban economic growth. Therefore, the cultural dimension is very important in urban QoL research (23).

Most of the existing studies on urban QoL assessment have served as tools for conducting rankings and making guides (24), and Providing guidance on making development policies. Naturally, their attention is primarily on cities: some deal with the QoL of a single city (14, 18, 25); some compare that of multiple cities (16, 26, 27); some draw comparisons between different areas within a city (28–30), and still some compare cities within a country (31). However, in recent years, there has been a growing trend toward researching the QoL assessment of counties as an administrative unit. For instance, Ma et al. analyzed the spatial patterns of the degrees of urban–rural integration in China's Gansu Province by assessing the quality of life in 87 counties in the province. Their research covers three QoL dimensions—economic, social and environmental (32).

Purely quantitative methods or hybrid methods combining qualitative and quantitative analysis have been used in urban QoL assessments. Those primarily oriented toward personal development mostly employed hybrid methods (18, 33), the most common of which is questionnaire survey (14, 19, 25, 27, 30). Those focusing on urban development mostly used quantitative methods, in which statistical analysis methods and tools such as importance performance analysis (IPA), information entropy, equalization index, structural equation modeling, and hierarchical multiple linear regression analysis have been widely applied (11, 32, 34). Another widely used tool is GIS, which has grown into an important work platform in urban QoL assessments involving spatial pattern analysis (28, 35). Also playing a crucial role in such assessments is spatial autocorrelation analysis (32, 35).

Now a popular tool in urban research (36), spatial autocorrelation analysis allows for the analysis of the dynamic evolution of urban spatial relationships under spatiotemporal sequences (37, 38), and can illuminate the characteristics of the region by analyzing the characteristics of surrounding areas. It provides a new perspective for the analysis of urban spatial characteristics (39, 40). At present, spatial

autocorrelation analysis in urban research is mainly applied in the understanding of topics related to urban environmental change, such as spatiotemporal change patterns of urban heat islands (41), spatial characteristics of urban atmospheric environmental efficiency (42, 43), spatial characteristics of urban ecosystem services (44), and urban and rural animal habitats. (45). More notably, the usefulness of spatial autocorrelation analysis in urban management research has also received recognition. Kim et al. used spatial autocorrelation analysis to interpret the regional spatial relationship of smart city services in South Korea (46). Balducci et al. used it to interpret the spatial pattern of the intelligent management of major towns in Italy (47). Li et al. used both global and local spatial autocorrelation analysis to investigate the spatial dynamic characteristics of regional economic disparity among cities in the Yangtze River Delta (40). Huang et al. interpreted the degree of spatial autocorrelation of housing transaction volumes in the counties and cities of Taiwan (48). Li and Derudder tried to use the spatial autocorrelation model to identify the population centers and sub-centers of Chinese cities and dissect the mechanism of the evolution of urban population centers (49). A study particular of note is that of Faka et al., who applied spatial autocorrelation analysis to urban QoL assessment at the local level to illuminate the characteristics of clustering in the urban QoL of Athens (35). The study provides new insights into how to analyze the spatial evolution of urban quality of life. The introduction of spatial autocorrelation analysis into QoL assessment is conducive to explaining the possible spatial correlation of quality of life changes. In other words, the characteristics of one region's quality of life, along with its patterns of change and the driving forces behind the change can be understood by analyzing the characteristics of the QoL of surrounding regions. Thus, spatial autocorrelation analysis can enrich and improve the methodology for QoL analysis.

Concerned with the QoL evolution in poor regions, this urban development study evaluates the QoL in Guizhou's impoverished districts and counties by means of quantitative analysis. The QoL assessment is realized through evaluating the four specific dimensions of economy, society, culture and environment. By comparing the quality of life of those places in the 3 years of 2000, 2010, and 2020, this study seeks to elucidate the distribution characteristics and evolution patterns of the quality of life in Guizhou's impoverished districts and counties. Through introducing spatial autocorrelation analysis into the spatio-temporal analysis of regional urban QoL, it sheds light on the possible spatial clustering of the quality of life of Guizhou's impoverished districts and counties and its change patterns. As such, it can help local authorities better understand their experience of development and make better policies to improve people's quality of life.

2. Data processing

2.1. Scope of the study

This study evolves around the mountainous Guizhou Province in southwestern China. Guizhou has long been designated as an economically backward province in China. Of its 88 districts and counties, 66 were on China's poverty list, making it the province with the largest poor population in the country. However, by November 2020, all 66 places had been successfully removed from the list, making Guizhou the province with the largest number of people lifted out of poverty in China. From the province with the largest impoverished population to the one with the largest population lifted from poverty, this change of Guizhou's status in China has undoubtedly been accompanied by a dramatic transformation in the life in Guizhou's historically impoverished districts and counties. This can be attested by the fact that the annual GDP of the province increased from 0.10 trillion yuan in 2000 to 1.79 trillion yuan in 2020 and its area of construction land expanded by 2,493 square kilometers over the same period. By analyzing the distribution characteristics and change patterns of the quality of life of Guizhou's impoverished districts and counties, the study can sum up the experience of successful development of those places, which may both serve the needs of Guizhou in consolidating its progress and be drawn on by other places around the globe when combating poverty. Thus, taking the 66 historically impoverished districts and counties of Guizhou Province as its subjects, this study attempts to analyze the evolution of the quality of life of those places in the two decades from 2000 to 2020, and explore the spatial correlations between different places in the evolution of their quality of life.

2.2. Data sources

The data used in this study mainly comes from China Statistical Yearbook (County-Level), which offers a comprehensive look into the socio-economic development of China's counties (and districts as an equivalent administrative unit). Additional data sources include *Guizhou Statistical Yearbook*, *China Energy Statistical Yearbook*, "Globeland30" (a global land cover (GLC) data product from the website GLOBALLANDCOVER), and the lists of Guizhou's national and provincial intangible cultural heritage items and protected cultural relics, which are published on the official website of the people's government of Guizhou Province.

2.3. Data processing (standardization)

Given the difference in the dimensions of various data, the research adopts the normalization method to render the data dimensionless. The formula for calculating positive indicators is as follows:

$$X'_i = \frac{X_i - X_{imin}}{X_{imax} - X_{imin}}$$

The formula for calculating negative indicators is as follows:

$$X'_i = \frac{X_{imax} - X_i}{X_{imax} - X_{imin}}$$

In the formula: X_i stands for the original statistic of category i in the index system of the QoL assessment of the districts and counties of Guizhou Province; iX_{imax} stands for the maximum value of the original statistics of category i in the index system of the QoL assessment; X_{imin} stands for the minimum value of the original

statistics of category i in the index system of the QoL assessment; iX'_i stands for the utility value of category i in the index system of the QoL assessment.

3. Research design and methodology

3.1. Quality of life assessment index system construction and weights setting

As is widely known, the economy, culture, society, and ecology of cities and towns together form an internally unified and organic whole. As such, urban QoL assessment needs to be approached with systematic thinking. To fully represent the levels of economic development, cultural prosperity, social stability and ecological health of a given place, this study constructed a QoL assessment index system comprising four secondary indicators, namely economic QoL index, cultural QoL index, social QoL index and environmental QoL index.

All the metrics and data cited in this study were obtained from the database for counties established by China's National Bureau of Statistics, the publicly accessible information released by the People's Government of Guizhou Province and the land cover data provided by GlobeLand30.

Among the four dimensions of quality of life measured in this study, economy provides the material foundation of a high quality life. The economic QoL must take into consideration both micro-factors such as income, savings and consumption, as well as the state of economic development as a macro-factor. As such, this study devised three third-level indicators of economic QoL, including income index, consumption index and vitality of industries index. The income index is calculated by considering the annual GDP of a place and the total savings of its residents. The consumption index is calculated by considering the amount of electricity consumption and the number of telephone subscribers at year-end. The vitality of industries index is calculated by factoring in the added values of the primary, secondary and tertiary sectors of the economy, the area occupied by facility agriculture and the number of industrial enterprises above designated size. Altogether, the three third-level indicators of economic QoL are represented by nine fourth-level ones.

Another QoL dimension examined in this study is culture, which forms the intellectual and spiritual foundation for a high-quality life. The study evaluates the cultural QoL of Guizhou impoverished districts and counties by considering three elements: the capacity of cultural transmission, the number of material cultural items and that of non-material cultural items. The capacity of cultural transmission is reflected in the number of students presently enrolled in schools. The numbers of material and non-material cultural items are represented by the numbers of tangible and intangible cultural heritage items respectively, which are designated by China's national cultural authority or its provincial divisions. In total, the cultural QoL of Guizhou's impoverished districts and counties are reflected in five fourth-level indicators.

A third QoL dimension evaluated in this study is social conditions, which are also indispensable when measuring quality of life. The study approaches social QoL from the three perspectives of employment, social welfare and medical services. The state of employment is examined by looking at the proportions of people employed in the secondary and tertiary sectors of the economy. Social welfare is reflected in the number of social welfare institutions as well as the number of beds provided by them. Medical services are assessed through counting the number of beds offered in health care facilities. All in all, the social QoL comprises four fourth-level indicators.

The environmental QoL index in this study considers not only the natural resources of a place, but also the level of environmental pollution it suffers. Altogether, this index is represented by three third-level indicators, namely green space resources, blue space resources and carbon emissions, which correspond with three fourth-level indicators. It is worth noting that carbon emissions are a reverse indicator (see Table 1). Besides, the study utilizes the AHP-Analysis Hierarchy Process to set the weights of the indicators.

3.2. Correlation analysis

The study uses Pearson Correlation Analysis to explain the correlations between the overall quality of life and the levels of economic development, cultural prosperity, social stability and ecological health in Guizhou's districts and counties across different periods. The Pearson correlation coefficient, also known as the product-difference correlation coefficient, is a statistical indicator that depicts the degree and direction of the linear correlation between two variables. The correlation coefficient is a dimensionless statistical indicator, and its value ranges from −1 to 1. When below zero, it indicates a negative correlation, and when above 0, it indicates a positive correlation. A zero means there is no correlation. The larger the absolute value of the correlation coefficient, the higher the correlation between the two variables.

3.3. Spatial autocorrelation analysis

Spatial autocorrelation analysis is classified into global autocorrelation analysis (also called Global Moran's I) and local autocorrelation analysis (or Local Moran's *I*). Both types of spatial autocorrelation analysis can be performed in the software ArcGIS. Through Global Moran's I, this study firstly determined whether the quality of life in Guizhou's districts and counties had a spatial autocorrelation, that is, whether places with high quality of life were surrounded by those of the same kind. If there was a global spatial autocorrelation in the quality of life, then the study would proceed to calculate the Local Moran's *I* to find out where of those places showed aggregations or were outliers in terms of quality of life.

3.3.1. Global Moran's *I* analysis

The study first performed a global spatial autocorrelation analysis on the QoL assessment results of Guizhou's districts and counties in 2000, 2010, and 2020. This was meant to determine whether there were spatial aggregations in the quality of life of those places. The global spatial autocorrelation analysis covered the overall QoL and the QoL as reflected in four specific dimensions—economy, culture, society, and environment.

The Global Moran's *I* was developed by Australian statistician Patrick Alfred Pierce Moran in 1948 (50). Based on the autocorrelation between the position of the elements and the attribute value in a global space, this index may classify global autocorrelation modes into three types—cluster mode, discrete mode, or random mode. Global

TABLE 1 QoL assessment index system and weights setting.

QoL dimensions	Indicators	Explanation
Economic QoL index (0.12)	Income index (0.35)	Annual GDP (10,000 yuan) (0.49)
		Balance of savings at year end (10,000 yuan) (0.51)
	Consumption Index (0.32)	Electricity consumption (kWh) (0.47)
		Number of telephone subscribers at year end (household) (0.53)
	Vitality of industries (0.33)	Added value of the primary sector of the economy (10,000 yuan) (0.25)
		Added value of the secondary sector (10,000 yuan) (0.16)
		Added value of the tertiary sector (10,000 yuan) (0.23)
		Area covered by facility agriculture (hectares) (0.06)
		Number of industrial enterprises above designated size (0.30)
Cultural QoL index (0.13)	Education (0.34)	Number of students enrolled in middle schools (person) (1.00)
	Intangible culture (0.45)	Number of national intangible cultural heritage items (0.24)
		Number of provincial intangible cultural heritage items (0.76)
	Material culture (0.21)	Number of major historical and cultural sites protected at the national level (0.45)
		Number of major historical and cultural sites protected at the provincial level (0.55)
Social QoL index (0.16)	Employment (0.35)	The proportions of residents employed in the secondary and tertiary sectors (1.00)
	Social welfare (0.40)	Number of social welfare institutions (0.72)
		Number of beds in social welfare institutions (0.28)
	Medical services (0.25)	Number of beds in health care facilities (1.00)
Environmental quality of life index (0.59)	Green space resources (0.47)	Area of cultivated land and land covered by forests, grass, or shrubs (hectares) (1.00)
	Blue space resources (0.01)	Area of waters and wetlands (hectare) (1.00)
	Carbon emissions* (0.52)	Annual carbon emissions (million metric tons) (1.00)*

*Indicates a reverse index, the weights are in parentheses.

autocorrelation analysis mainly evaluates the significance of autocorrelation by calculating the Moran's *I* value, the *z*-score and the value of *p* (probability).

Its calculation formula is as follows:

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n}\sum_{j=1}^{n} W_{i,j} Z_i Z_j}{\sum_{i=1}^{n} Z_i^2}$$

In it, Z_i is the deviation between the attribute of element i and the mean value ($x_i - \bar{X}$); $W_{i,j}$ is the spatial weight between elements i and j; n equals the total number of elements; and S_0 is the aggregation of all spatial weights.

$$S_0 = \sum_{i=0}^{n}\sum_{j=1}^{n} W_{i,j}$$

The z-score is calculated through the following formula:

$$Z_I = \frac{I - E[I]}{\sqrt{V[I]}}$$

In it:

$$E[I] = -1/(n-1)$$

$$V[I] = E\left[I^2\right] - E[I]^2$$

Typically, the Global Moran's *I* is between −1 and 1. If the Moran's *I* is larger than zero, it indicates a positive spatial correlation, and the larger the value, the stronger the correlation. A Moran's *I* below zero suggests a negative spatial correlation. The smaller the value, the greater the spatial difference. If the Moran's *I* is zero, then the spatial correlation is random.

The value of *p* indicates probability. For pattern analysis tools, the value of *p* represents the probability that the observed spatial pattern is created through a random process. A small value of *p* suggests that the observed spatial pattern is unlikely to be generated through random processes (in other words, such was a small probability event).

The *z*-score represents the deviation from the standard. The larger its absolute value, the higher the degree of clustering. A *z*-score close to zero indicates that no significant clustering exists within the studied area. A positive *z*-score indicates a cluster of high values. A negative *z*-score indicates a cluster of low values. Therefore, by analyzing the *z*-score and value of *p* yielded by the calculation tool in ArcGIS, the confidence degree of the spatial autocorrelation of the calculation results can be determined (see Table 2).

3.3.2. Local Moran's *I* analysis

By calculating the Global Moran's *I*, the overall characteristics of aggregation in the spatial distribution of the quality of life-related indicators of Guizhou Province can be known, but these

overall characteristics cannot show the specific clustering locations of the indicators in the space. Therefore, the study needed to present the spatial distribution of the clusters of the QoL indexes of Guizhou's districts and counties by calculating the Local Moran's *I*.

The Local Moran's I was proposed by professor Luc Anselin at Arizona State University in 1995 (51). The formula for calculating this index for each element is as follows:

$$I_i = \frac{x_i - \bar{X}}{S_i^2} \sum_{j=1, j\neq i}^{n} w_{ij}\left(x_j - \bar{X}\right)$$

In it, x_i is an attribute of element i; $\bar{X}$ is the mean value of the corresponding attribute; and w_{ij} is the spatial weight matrix between elements *i* and *j*.

$$S_i^2 = \frac{\sum_{j=1, j\neq i}^{n}\left(x_j - \bar{X}\right)^2}{n-1}$$

Value *n* stands for the total number of elements.

After calculating the Local Moran's *I*, this study located the hot spots (or high-value clusters) and cold spots (or low-value clusters) of the QoL indexes of Guizhou's counties and districts in the 3 years on the maps. The data was then used for further comparative analysis. Here, high values mainly refer to outliers surrounded by low values, while low values mainly represent outliers surrounded by high values.

TABLE 2 Global spatial autocorrelation confidence degree analysis.

z-score	Value of *p*	Confidence degree
< −1.65 or >+1.65	<0.10	90%
< −1.96 or >+1.96	<0.05	95%
< −2.58 or >+2.58	<0.01	99%

4. Research outcome

4.1. Analysis of the evolution of quality of life

4.1.1. Analysis of the evolution of the overall QoL

As shown in Figure 1, in the two decades between 2000 and 2020, the overall quality of life in Guizhou's impoverished districts and counties improved significantly. The places that have experienced the most significant QoL improvement are clustered in the southeast of the province. However, four districts and counties have seen their quality of life decline slightly over the two decades.

From a spatial point of view (as shown in Figure 2) in 2000, among the impoverished districts and counties of Guizhou province, those with a high quality of life were clustered in the coal-rich northwest. In the decade between 2000 and 2010, the impoverished districts and counties where the quality of life rose the fastest were in Guizhou's southeast, northwest, north and northeast. By 2010, the places with a high overall quality of life among Guizhou's impoverished districts and counties had shifted to its southeast. A prominent example is Liping County, which achieved the most dramatic increase in its overall quality of life and came to be ranked No. 1 among Guizhou's impoverished districts and counties in this regard. In the decade between 2010 and 2020, Guizhou's impoverished districts and counties that saw the fastest improvement in quality of life were

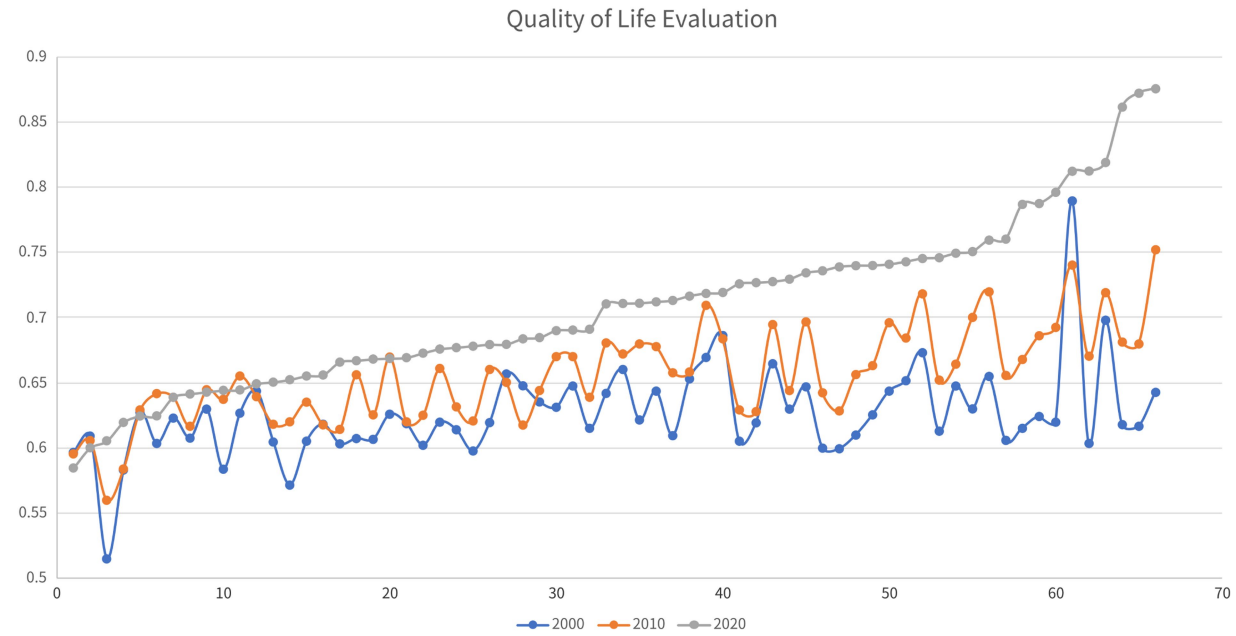

FIGURE 1
Analysis of the evolution of the quality of life of Guizhou's districts and counties from 2000 to 2020.

all in the southeast. In 2020, the vast majority of Guizhou's historically impoverished districts and counties with the highest quality of life among peer places were in the southeastern part of the province. It can be seen that in the two decades between 2000 and 2020, the places with a higher quality of life among Guizhou's historically impoverished districts and counties shifted from the northwest of the province to its southeast, which is rich in natural ecological landscapes and ethnic minority culture.

4.1.2. Analysis of the evolution of the specific dimensions of quality of life

4.1.2.1. Analysis of the evolution of the economic QoL

As shown in Figure 3, in the two decades from 2000 to 2020, the economic QoL of the 66 impoverished districts and counties of Guizhou province declined to varying degrees. In the first decade, the economic QoL of 37 of the 66 places worsened, and in the second decade, 43 places suffered declines in their economic QoL. Over the entire period, the overall economic QoL of 40 districts and counties declined.

In terms of spatial distribution (see Figure 4), in 2000, the historically impoverished districts and counties of Guizhou Province with a high economic QoL were mainly located in its western, northern and eastern regions. In 2010 and 2020, the impoverished districts and counties with a relative high economic QoL remained concentrated in western and eastern Guizhou. In the decade from 2000 to 2010, the economic QoL of Guizhou's impoverished districts and counties improved rapidly in the western and central regions of the province, whereas in the following decade ending in 2020, such an improvement happened not only to those two regions, but also to its north and east. Southern Guizhou remained an area with a low economic QoL.

4.1.2.2. Analysis of the evolution of cultural QoL

In the two decades from 2000 to 2020, especially the second one, the cultural QoL in Guizhou's impoverished districts and counties has increased by leaps and bounds (see Figure 5). At the same time, the spatial distribution of places with a relative high quality of cultural life undergone significant changes. As shown in Figure 6, in 2000, such places were all located in the western part of the province. In 2010, although Guizhou's impoverished districts and counties with high

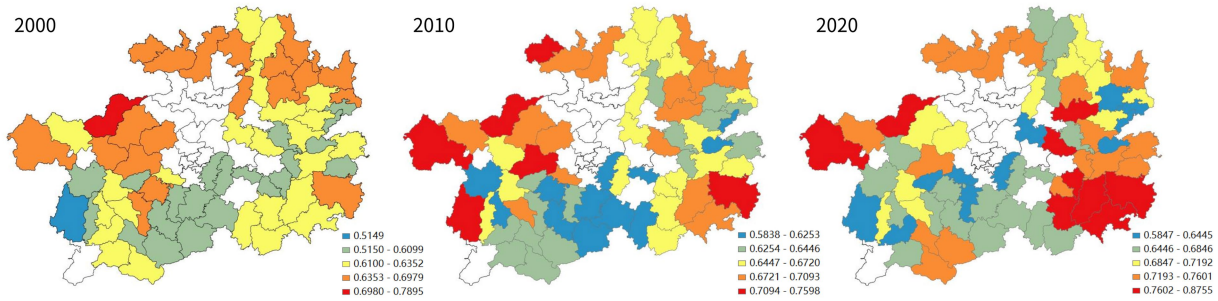

FIGURE 2
Spatial analysis of the changes in quality of life in Guizhou's districts and counties.

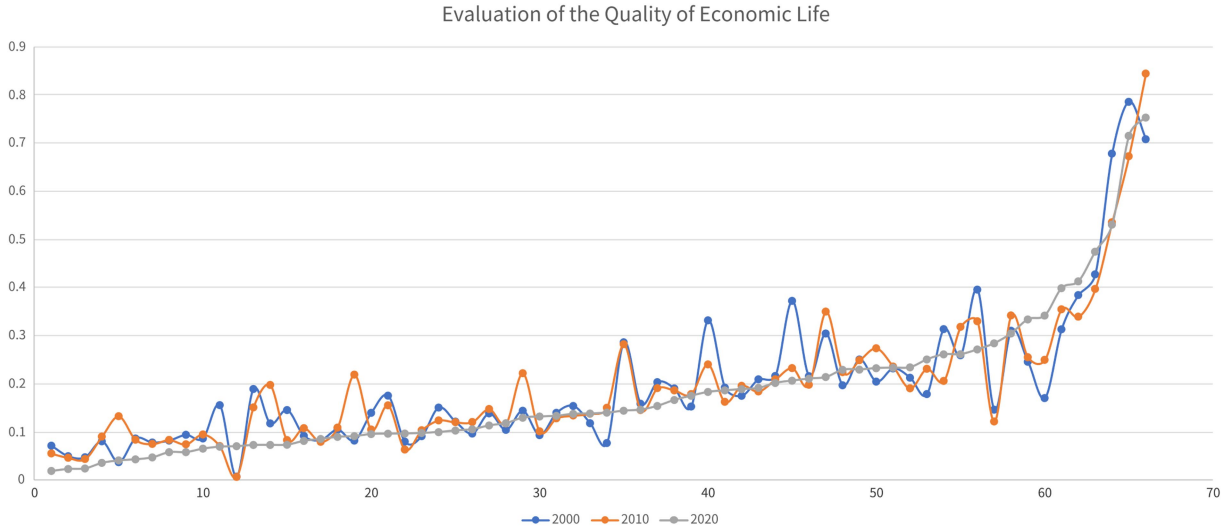

FIGURE 3
Analysis of the evolution of the economic QoL of Guizhou's districts and counties from 2000 to 2020.

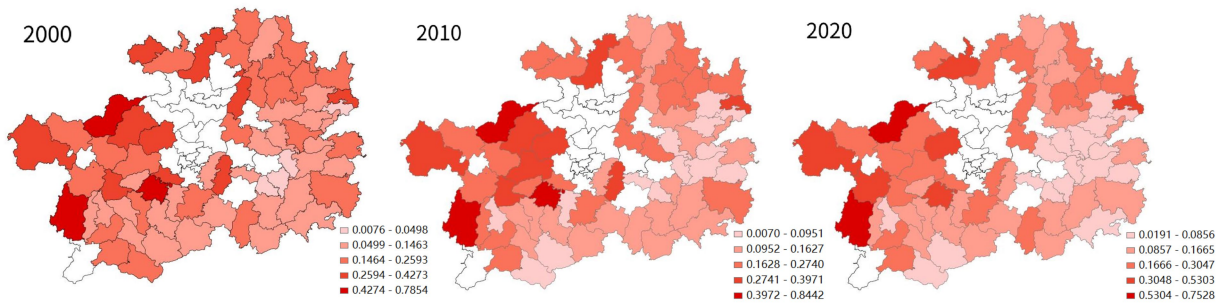

FIGURE 4
Spatial analysis of changes in the economic QoL of Guizhou's districts and counties.

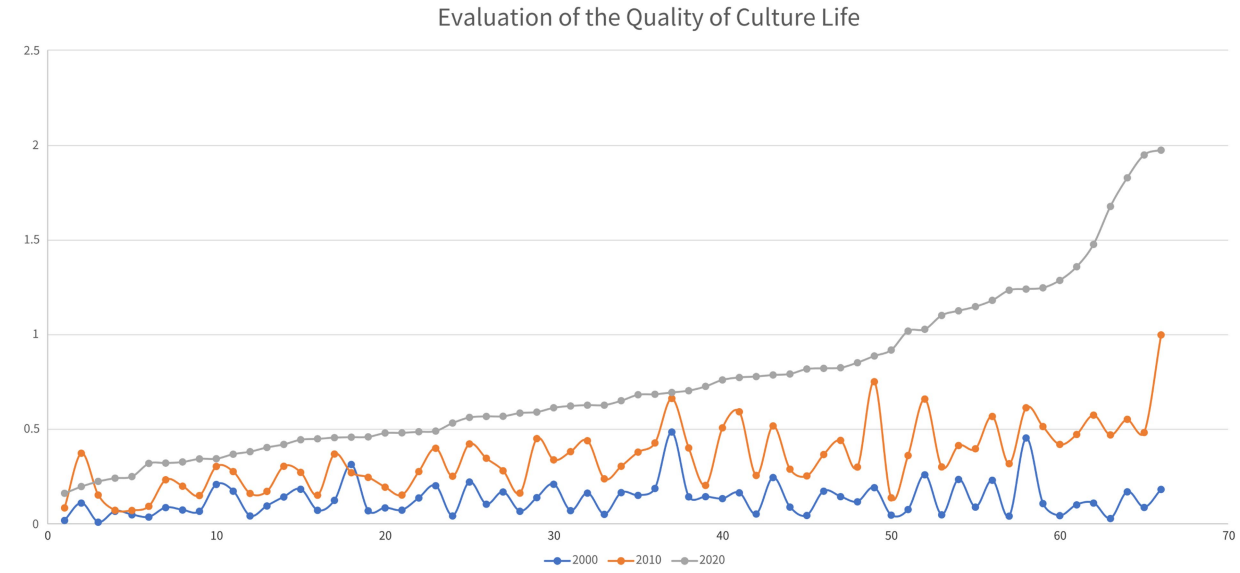

FIGURE 5
Analysis of the evolution of cultural QoL of Guizhou's districts and counties from 2000 to 2020.

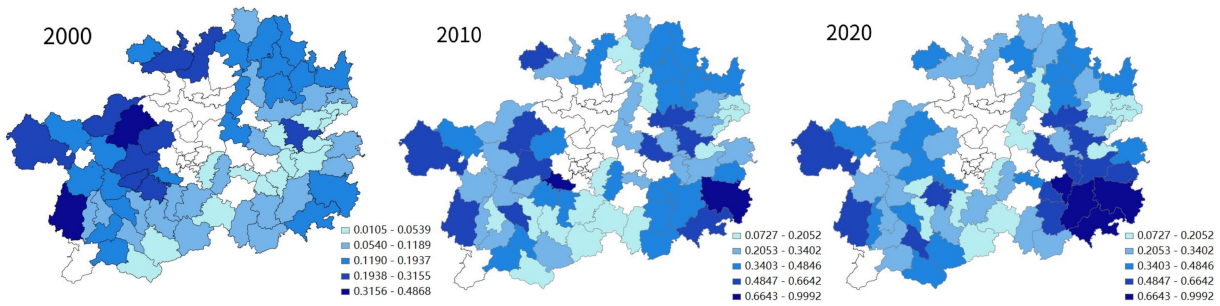

FIGURE 6
Spatial analysis of the changes in cultural QoL of Guizhou's districts and counties.

quality of cultural life were still mostly in its western part, Liping County in the southeast topped this list. By 2020, the districts and counties with high cultural QoL in Guizhou had been completely relocated to the southeastern part of the province. Obviously, in the two decades, Guizhou's impoverished districts and counties with high cultural QoL in Guizhou have been shifted from its west to its southeast.

4.1.2.3. Analysis of the evolution of social QoL

In the two decades between 2000 and 2020, the social QoL of the impoverished districts and counties of Guizhou Province has generally improved. In the decade between 2000 and 2010, 44 of the 66 impoverished districts and counties achieved improvement in their social QoL, while in the next decade, the social QoL of 55 impoverished districts and counties improved (see Figure 7).

In terms of spatial distribution, no matter in 2000, 2010, or 2020, among Guizhou's impoverished districts and counties, the ones with high social QoL were concentrated in the northwest of the province (see Figure 8). In the decade between 2000 and 2010, the impoverished districts and counties with rapid improvement in the quality of social life were in the west, north and east of Guizhou. In the next decade, the western or northern places in Guizhou saw the fastest improvement in their quality of social life.

4.1.2.4. Analysis of the evolution of environmental QoL

The environmental QoL of Guizhou's impoverished districts and counties generally (39 of all 66 places) went through slight declines during the decade from 2000 to 2010. In the next decade, all 66 impoverished districts and counties of Guizhou Province suffered notable declines in their environmental QoL (see Figure 9).

Specifically, as shown in Figure 10, in 2000, the impoverished districts and counties in Guizhou with poor environmental QoL were all located in the southwest of the province; In 2010 and 2020, these places still had the worst environmental QoL. On the other hand, in 2000, Guizhou's impoverished districts and counties with high environmental QoL were located in the southeast, east and northwest of the province. In 2010, the impoverished districts and counties with relatively high environmental QoL were located in the east, northwest and north of Guizhou; In 2020, the places that made the list were located in Guizhou's east, south and north.

4.1.3. Correlation analysis of the evolution of quality of life

As shown in Table 3, the Pearson correlation coefficient analysis was performed in the assessment of the overall QoL and the four secondary QoL indicators of Guizhou's impoverished districts and counties in 2000, 2010, and 2020. It was found that there are huge differences in the correlations between the overall quality of life and the economic QoL, cultural QoL, social QoL and environmental QoL in the three different years.

In 2000, the overall quality of life in Guizhou's impoverished districts and counties showed a clear positive correlation with their

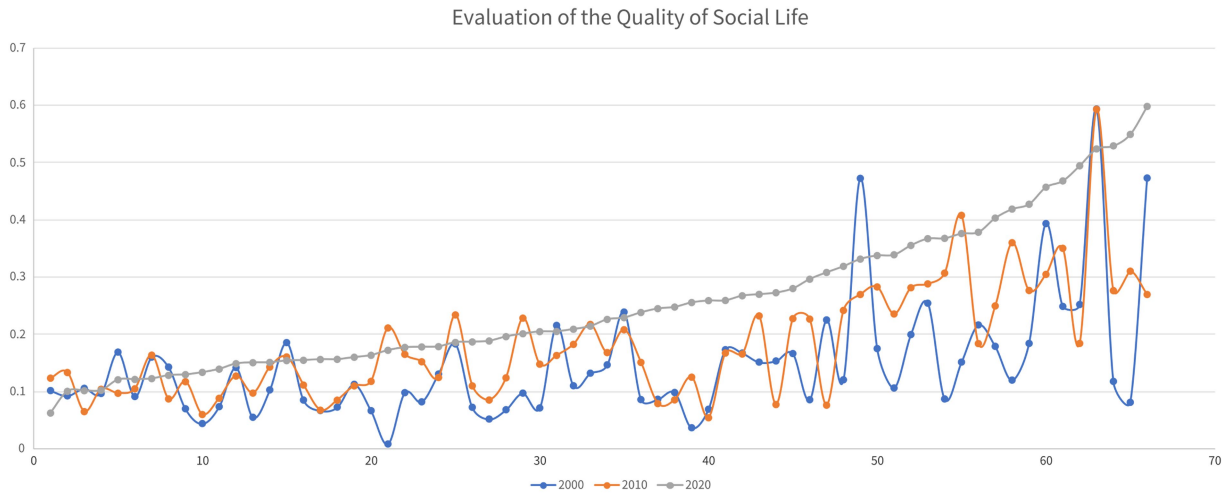

FIGURE 7
Analysis of the evolution of social QoL of Guizhou's districts and counties from 2000 to 2020.

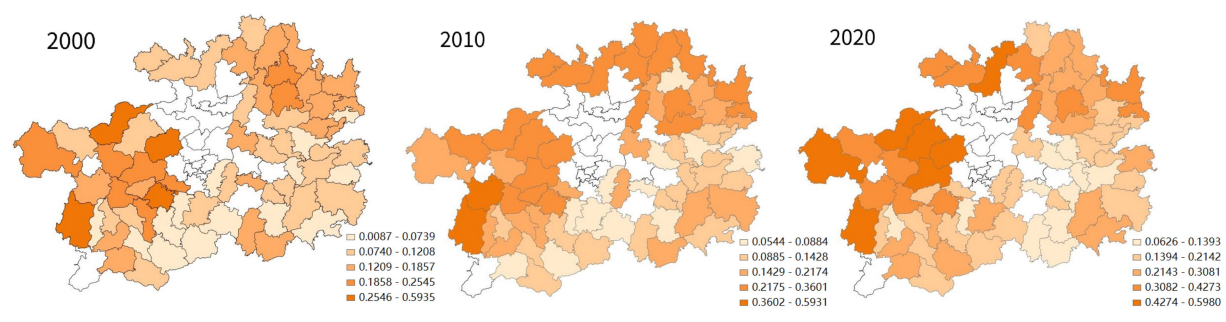

FIGURE 8
Spatial analysis of social QoL changes in districts and counties of Guizhou Province.

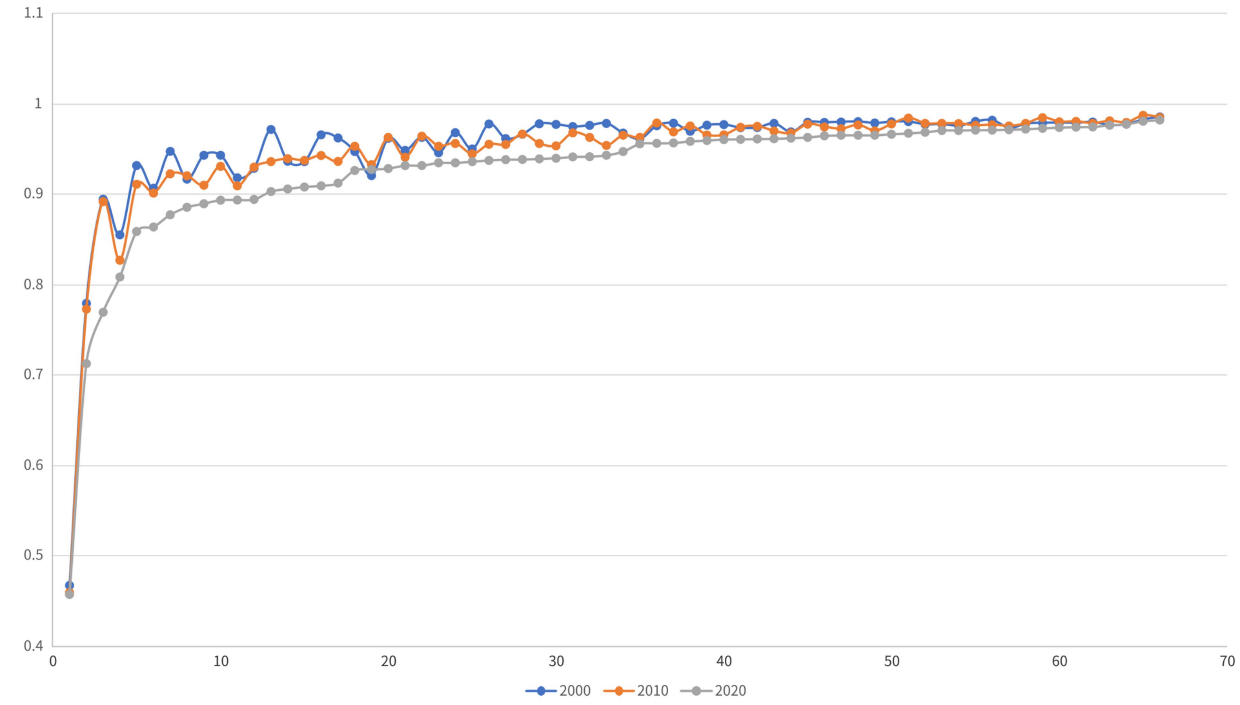

FIGURE 9
Analysis of the evolution of the environmental QoL of Guizhou's districts and counties from 2000 to 2020.

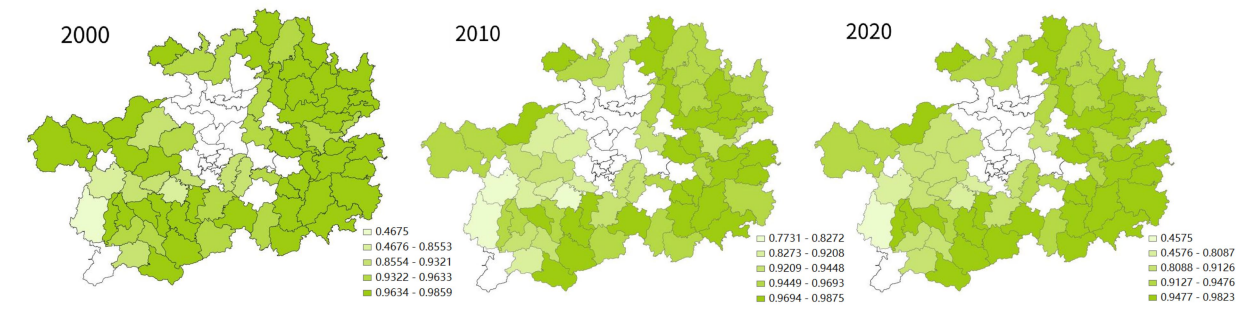

FIGURE 10
Spatial analysis of changes in the environmental QoL of Guizhou's districts and counties.

economic, social and environmental QoL, especially the first of the three. However, in 2010, while the overall quality of life of Guizhou's impoverished districts and counties did not show a significant correlation with the local environmental QoL, its positive correlations with the economic QoL, cultural QoL and social QoL all increased significantly. Of the three specific QoL dimensions, its positive correlation with the cultural QoL was the most prominent. It is worth noting that in 2020, the overall quality of life of Guizhou's impoverished districts and counties showed the strongest positive correlation with the local cultural QoL, followed by the environmental QoL, while it exhibited no significant correlation with their economic or social QoL. It is obvious that in different years, the secondary QoL indicators affecting the overall quality of life of Guizhou's impoverished districts and counties were not the same, which implies that in the two decades, the development models of those places experienced constant evolution.

4.2. Quality of life spatial autocorrelation analysis

4.2.1. Quality of life global spatial autocorrelation analysis

By calculating the Global Moran's *I*s, *z*-scores and value of *p*s of the overall QoL, economic QoL, cultural QoL, social QoL and environmental QoL of Guizhou's impoverished districts and counties in 2000, 2010 and 2020, we can determine whether there existed global spatial autocorrelation, or the phenomenon of spatial clustering,

TABLE 3 Analysis of Pearson correlation coefficient between the overall quality of life evaluations and the secondary indexes.

Year and index type	QoL assessment in 2000
Economic QoL in 2000	0.462**
Cultural QoL in 2000	0.373**
Social QoL in 2000	0.350**
Environmental QoL in 2000	0.394**
/	QoL assessment in 2010
Economic QoL in 2010	0.558**
Cultural QoL in 2010	0.739**
Social QoL in 2010	0.580**
Environmental QoL in 2010	0.022
/	QoL assessment in 2020
Economic QoL in 2020	−0.005
Cultural QoL in 2020	0.776**
Social QoL in 2020	0.212
Environmental QoL in 2020	0.381**

**$p < 0.01$.

TABLE 4 The Global Moran's *I*s, *z*-scores, and value of *p*s of QoL across the years.

Year and index type	Moran *I*	z-score	*p*-value
Overall QoL in 2000	0.272379	3.772652	0.000162
Overall QoL in 2010	0.189075	2.236849	0.025296
Overall QoL in 2020	0.206635	2.801927	0.005080
Economic QoL in 2000	0.108392	1.591382	0.111524
Economic QoL in 2010	0.205945	2.893757	0.003807
Economic QoL in 2020	0.229392	3.129172	0.001753
Cultural QoL in 2000	0.339045	4.516181	0.000006
Cultural QoL in 2010	0.248641	3.308746	0.000937
Cultural QoL in 2020	0.051	0.0828129	0.407597
Social QoL in 2000	0.103887	1.544800	0.122395
Social QoL in 2010	0.357943	4.715855	0.000002
Social QoL in 2020	0.492622	6.256091	0.000000
Environmental QoL in 2000	0.111264	2.372154	0.017685
Environmental QoL in 2010	0.266849	3.700970	0.000215
Environmental QoL in 2020	0.189966	3.094898	0.001969

in different indexes. As shown in Table 4, in terms of overall QoL of Guizhou's historically impoverished districts and counties, no matter in 2000, 2010 or 2020, there was consistently an obvious positive spatial correlation, meaning that high values were clustered together, as were low values, indicating a positive spatial correlation and thereby a conspicuous spatial clustering. However, the economic QoL indexes and social QoL indexes of Guizhou's impoverished districts and counties did not exhibit obvious spatial clustering in 2000 (The underlined figures in Table 4 indicate that there was no obvious spatial clustering). Only in 2010 and 2020, there were clear spatial clustering in these indexes. Meanwhile, the cultural QoL indexes of Guizhou's impoverished districts and counties exhibited spatial clustering in 2000 and 2010, which were, however, gone in 2020, while the environmental QoL indexes exhibited consistent positive spatial correlations across the 3 years.

In other words, in the 3 years, the overall QoL and the environmental QoL in those places maintained positive spatial correlations, while the spatial clustering of the economic, social, and cultural QoL underwent changes. For the first two, the spatial clustering, once non-existent, came to exist later; and for the clustering of the cultural QoL, the change was a reverse one.

4.2.2. Quality of life local spatial autocorrelation analysis

A Local Moran's I Analysis was performed on the various indexes in the QoL assessment of the impoverished districts and counties of Guizhou Province in 2000, 2010, and 2020, and the corresponding hot spots and cold spots can be presented on maps (see Figure 11).

As far as the overall quality of life of Guizhou's impoverished districts and counties in the three different years is concerned, the high-value hot spots experienced a shift from the west to the southeast of the province, and the low-value cold spots first spreaded within the southwest and then largely dissolved. Such processes also took place in the spatial clustering evolution of the cultural QoL. Across the three different years, the cultural QoL hotspots among Guizhou's impoverished districts and counties also relocated from the west to the southeast of the province, while the cold spots gradually vanished.

A different pattern existed in the evolution of the economic QoL of Guizhou's impoverished districts and counties. The high-value hot spots in this dimension consistently concentrated in the mid-western regions of the province, while the low-value cold spots gradually formed in the mid-eastern regions; The high-value hotspots of social QoL gradually formed in the mid-western and northern regions of Guizhou, while the low-value cold spots gradually disappeared. Finally, the southwestern part of Guizhou Province was consistently a low-value cold spot in terms of environmental QoL in the two decades.

5. Discussion and conclusion

5.1. Discussion

Guizhou, as the province with the largest number of people overcome poverty in China, has witnessed great changes in the quality of life of its 66 impoverished districts and counties from 2000 to 2020. These changes were also a summary of Guizhou's unique experience in its development of society, economy, culture and living environment. According to the research outcomes, the development of the overall quality of life in Guizhou was driven by its unique regional ethnic culture and historical culture. However, from the perspective of time distribution, the traction role of cultural quality of life only played an obvious role from 2010 to 2020. From 2000 to 2010, Guizhou mainly promoted the overall quality of life by economic quality of life. In terms of spatial distribution, the overall quality of life in Guizhou was also uneven. The western region had obvious advantages in economic quality of life, while the southeastern region had a strong force in cultural quality of life.

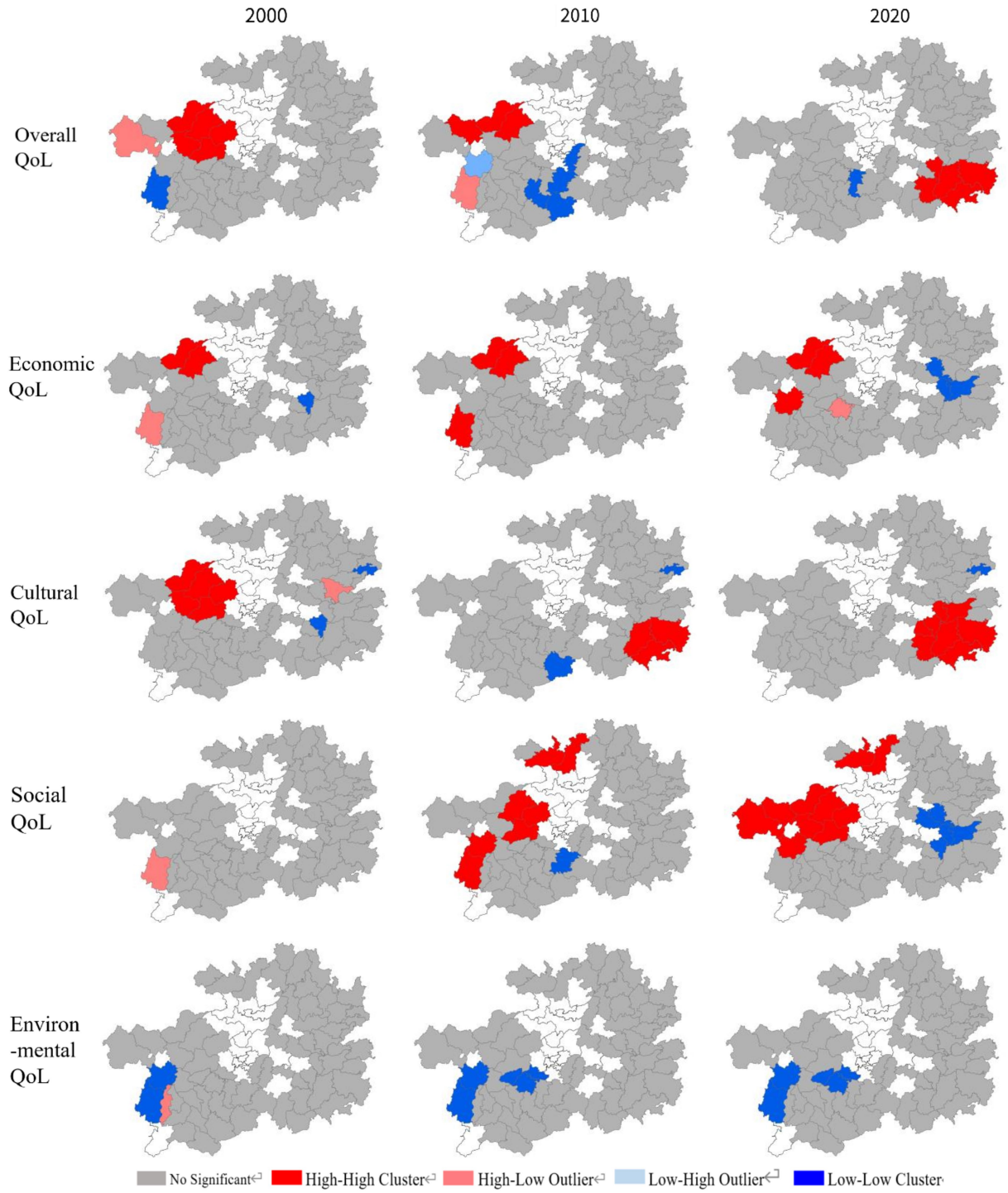

FIGURE 11
Analysis of the cold and hot spots in the QoL assessments of the impoverished districts and counties of Guizhou Province.

The improvement of the overall quality of life in Guizhou also had obvious spatial aggregation characteristics from 2000 to 2020, which was reflected in the disappearance of the spatial aggregation characteristics of the cultural quality of life on the one hand, and the prominence of the spatial aggregation characteristics of the social and economic quality of life on the other hand. The detailed discussion is as follows:

5.1.1. The overall quality of life of Guizhou's impoverished districts and counties improved over the two decades from 2000 to 2020, while their four specific dimensions of quality of life saw highly varied changes

As shown in the overall QoL assessment results, 87.9% of Guizhou's impoverished districts and counties experienced a

significant improvement in 2000–2020. However, by and large, the economic QoL and the environmental QoL both underwent noticeable declines: 60.6% of all the places studied in the former aspect and 97.0% in the latter. Thus, the improvement in the overall QoL of Guizhou's impoverished districts and counties were presumably mainly driven by the substantial betterment of their social QoL and cultural QoL.

5.1.2. There existed wide gaps in quality of life between the east and the west among Guizhou's impoverished districts and counties

In terms of spatial distribution, the improvement of overall QoL in Guizhou's impoverished districts and counties was rather uneven. While it happened in the west, east and north of the province, the south stagnated throughout the two decades. When it comes to the specific dimensions of quality of life of Guizhou's impoverished districts and counties, a high economic QoL and social QoL were consistently characteristic of the western part of the province; a high cultural QoL, as a regional feature, shifted from the west to the southeast of the province; and a poor environmental QoL remained typical of western Guizhou. It can be seen that from 2000 to 2020, the social QoL and economic QoL of western Guizhou stayed relatively high. However, the improvement of its cultural QoL lagged that of other regions in the province. Also consistently low was the environmental QoL of this region. In general, the impoverished districts and counties in western Guizhou enjoyed a higher economic QoL and social QoL than similar places within the province, while the southeastern region had a higher cultural QoL and environmental QoL.

5.1.3. Different driving forces for the evolution of quality of life of Guizhou's impoverished districts and counties in different years

According to the results of the correlation analysis, in 2000, the main driving force behind the improvement of the overall quality of life in Guizhou's impoverished districts and counties was the economic QoL. In 2010, it was the cultural QoL that played the same role, which was consolidated in 2020. Therefore, the main driving force behind the improvement in the overall QoL of Guizhou's impoverished districts and counties changed from the economic QoL into the cultural QoL.

5.1.4. The spatial aggregation characteristics of the quality of life of Guizhou's impoverished districts and counties evolved over time

The global spatial autocorrelation analysis suggests that the overall quality of life of Guizhou Province consistently showed obvious characteristics of spatial aggregation in the two decades between 2000 and 2020. Meanwhile, while its economic QoL and social QoL did not show similar characteristics in 2000, such characteristics were present in these two dimensions in both 2010 and 2020. This indicates that a spatially clustered economic development and social development gradually formed amid the improvement of the overall QoL of Guizhou's impoverished districts and counties. On the other hand, the opposite process happened in the development of Guizhou's cultural QoL. While it exhibited obvious characteristics of spatial clustering in 2000, such characteristics were gone in 2020. This suggests that the development of the cultural QoL of Guizhou's impoverished districts and counties was increasingly a spatially even phenomenon. Due to the uneven distribution of natural resources, the environmental QoL of Guizhou impoverished districts and counties remained spatially clustered.

According to the results of local spatial autocorrelation analysis, the distribution of the cold and hot spots both in the overall QoL and in the four specific dimensions of Guizhou's impoverished districts and counties showed different characteristics over time. The overall QoL showed different characteristics of spatial aggregation in the three different years. In 2000, the impoverished places with high overall quality of life were clustered in western Guizhou. Such a clustering was less obvious in 2010. And by 2020, it had been relocated to the southeastern region. This development implies that there were interlinked changes in the strategies for improving the quality of life in impoverished districts and counties in various regions. Based on the analysis of the cold and hot spots of the four specific QoL dimensions, it can be inferred that Guizhou's southeast boasted a clustering of cultural resources, whereas the west enjoyed a linkage between its economic development and its social development. In addition, a low environmental QoL continued to be problematic for the southwest. All in all, the local spatial aggregation characteristics of the four specific dimension of quality of life of Guizhou's impoverished districts and counties can reveal the potential advantages of those places when trying to improve their quality of life.

5.2. Conclusion

By comparing the quality of life of 66 historically impoverished districts and counties of Guizhou province in 2000, 2010 and 2020, the study sums up the distribution characteristics and evolution patterns of the quality of life in those places in the four aspects of economy, culture, society and environment. Both the distribution characteristics and evolution patterns of QoL are visualized through Geographic Information System (GIS). The study introduces spatial autocorrelation analysis into QoL assessment, and examines the change process of quality of life from the angel of spatial agglomeration. This new approach is particularly useful in analyzing QoL transformation and its interregional correlation and can be widely applied in various QoL assessments and related research projects. One notable advantage of this approach is that it can present the similarities and differences in the QoL evolution between regions in a straightforward manner. Thus, it can be used to reveal the potential for coordinated development between regions, which can help authorities formulate development strategies that are customized based on local conditions and needs.

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.

Author contributions

JY, JD, and HY: conceptualization. JY, HY, and JD: methodology and validation. JY, CC, and HY: software and visualization. JY and HY: formal analysis, writing—original draft preparation, writing—review and editing. JY, HY, and TC: resources and data curation. JD and JY: supervision. All authors have read and agreed to the published version of the manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Impact of green space on residents' wellbeing: A case study of the Grand Canal (Hangzhou section)

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Introduction: In this study aimed to discuss the importance of the combination of cultural heritage management and green development for urban development by analyzing the upgrading and renovation of the Grand Canal (Hangzhou section) as a successful case. In recent years, green development has risen to prominence as a paradigm shift. Additionally, culture, as an engine to drive urban development, has received more attention.

Methods: This research used a hybrid approach to examine the importance of combining green development with cultural heritage management. The qualitative method was an interview analysis of 13 residents living in the Hangzhou section of the Grand Canal. Based on the analysis of multiple water quality variables in Hangzhou from 1998 and 2014 to 2021, the empirical results proved that it is feasible to integrate green development (environment and economy) into the cultural heritage management of the case study area.

Results and discussion: The results further prove that only through an understanding of the relationship between cultural heritage and green development can a virtuous cycle of development be created, thereby promoting the continuous development of a unique and historically significant urban area. The results of this study suggest that, in the development of mega-cities, although the preservation and inheritance of historical and cultural heritage conflicts with the green development of modern cities, a successful example has been explored in Hangzhou, including grassroots governance efforts like Gongshu District. There, the two factors can be mutually compatible and promote each other, enhancing the well-being and happiness of local residents.

KEYWORDS

green development, dynamic management, water quality, cultural heritage management, urban

1. Introduction

The significance of green development is clear from the considerable research exploring its determinants, sustainability (1), Green New Deal (2), and ecological civilization construction (3). Despite these studies discussing the influencing factors of a green economy, more attention should be paid to the connection between culture and green development. After the Rio Summit (4), the global society has been facing a dual challenge: expanding economic opportunities and addressing environmental pressures. Green development is the intersection of these two challenges, achieving a combination of both. Green development is a paradigm innovation based on traditional development (5), which takes environmental resources as an intrinsic element of economic development (6). Green development is intended to ensure sustainable economic, social, and environmental development. It continues to provide the environmental resources and services upon which the wellbeing of the public depends.

There is a close connection between green development and cultural resources. In the practice of green development, the protection and utilization of cultural resources are two very important aspects.[1] According to the Free Dictionary, green development refers to an approach to sustainable development[2] that considers environmental concerns and the efficient use of resources, such as land, energy, and water, and also involves the preservation of cultural and archeological resources. By incorporating environmental responsiveness, green development promotes the wellbeing of the environment and the surrounding communities. This approach to development not only benefits human and natural communities but also promotes cultural development. Additionally, green development is economically viable, providing a sustainable and responsible path for development (7). While remaining economically viable, green development benefits human and natural communities as well as cultural development. By integrating the cultural heritage with green development programs, such as environmental protection measures, national legislation outlines steps to preserve cultural heritage. Furthermore, for culture, green represents sustainability, i.e., the sustainability of cultural development is related to the preservation of cultural beliefs, cultural practices, cultural heritage preservation, culture as its entity, and any particular culture in the future (8–10).

Several studies (9, 10) on cultural heritage management have been published, examining the links between continued exposure to surrounding green development and cultural heritage management. Several studies found an inevitable need in the current socio-economic environment, incorporating the concept of green development in urban development, integrating with the city's cultural heritage, and reinvigorating the links between the urban cultural heritage and its natural environment (11). Most studies investigated the connection between the environment and cultural heritage, tracking how to perceive the role and importance of culture in green development. National and international efforts to promote green development as a new approach to manage cultural heritage have been intensifying.

It is important to consider a range of perspectives and factors when examining the links between the surrounding green development and cultural heritage management. This can help ensure that the decision-making processes are inclusive, equitable, and considerate of a broad range of values and priorities. The links between the surrounding green development and cultural heritage management are complex and multifaceted, and there are several aspects that are often overlooked or left out of the discussion. The preservation of cultural heritage and green spaces is often linked to broader historical and systemic factors. Examining the links between these factors and the management of green development and cultural heritage can help identify and address the underlying root causes of issues.

In December 2015, the International Conference on "Culture for Sustainable Cities" organized by the United Nations was held in Hangzhou, using the "Hangzhou Outcomes" to focus the spotlight on the power of culture for sustainable urban development (11). Its effects make the management of cultural heritage more challenging. The successful construction of Hangzhou can be attributed to its focus on sustainable development, cultural preservation, and internationalization, all of which have contributed to the city's economic growth and high quality of life for its residents; thus, the construction of Hangzhou is considered to be a successful model of coastal open cities in China. The Grand Canal is the greatest masterpiece of hydraulic engineering achievement in the history of society, creating the largest project in the world (12). In 2014, the Grand Canal was successfully inscribed on the World Heritage List (12).

The Grand Canal was built gradually over a long period, and its introduction is complex and not simple. It is a huge inland waterway system, running from Beijing in the north to Zhejiang province, Hangzhou city in the south, crossing eight provinces (12). It has contributed significantly to China's economic stability and prosperity over the eras and is still one of the main internal communication channels at present (12). Chinese President Xi Jinping has emphasized that "The Grand Canal is a precious heritage left to human beings by our ancestors, and it is a flowing culture, which should be well protected, inherited, and utilized" (13). Xi also emphasized that the preservation of the Grand Canal's cultural heritage should be integrated with the promotion of ecological and environmental protection, the safeguarding and restoration of renowned cities and towns along its route, the development of cultural tourism, and the modernization of canal navigation. These efforts aimed to create favorable conditions for the economic and social progress of the regions along the Grand Canal and to enhance the wellbeing of the people who live there (13).

The Grand Canal (Hangzhou section) has been chosen as a case study for this research since such a comprehensive conservation initiative has successfully integrated cultural heritage management and green development into sustainable urban development and has come to serve as an excellent model. In fact, the Grand Canal's other sections have accomplished well in terms of conservation. This research concentrates on analyzing the Hangzhou section due to space limitations and the need for the author's observations.

Despite the cultural projects' potential to stimulate local economic development, less attention has been given to integrating the existing cultural heritage management with green development. This research is structured into three parts. First, it provides a review of the current theory of green development. Second, by analyzing the policy background of Hangzhou and the discourse of the Grand Canal construction (Hangzhou section), this research clarifies how local government engages in green development. The third part sheds light on how the local government made relevant policies to integrate green development into the cultural heritage management of the case study area and the unique kind of green development represented by these specific cultural heritage sites will be examined. This research will also include interviews with Grand Canal residents and the use of empirical cases to demonstrate the importance of integrating green development with cultural heritage management. The authors argue that this case study is highly replicable and can serve as an exemplar for other countries seeking to integrate cultural management of the Grand Canal heritage with urban green development.

1 Qinghai Province International Internet News Center. Study on green development by green culture. Qinghai News.

2 Zhang Jianglin. Green development: a strategic concept of sustainable development.

2. Literature review

2.1. Green development

"Green development" generally refers to a sustainable approach to urban planning and development that aims to minimize environmental impact and promote ecological sustainability (14). The 1960s and 1970s saw a significant increase in awareness and concern about environmental issues, particularly with the publication of Rachel Carson's book "Silent Spring" in 1962 (15). This development helped to catalyze the modern environmental movement and led to the first Earth Day in 1970, which mobilized millions of people to call for greater environmental protection (16). Western societies first began to pay attention to the relationship between economic growth and environmental capacity in the late 17th century, and this period was the germ of the idea of green development (17). A new stage in rebuilding political discourse in response to ecological problems and environmental movements is represented by green growth and a green economy (18). As noted by the emergence of "ecological economics" (19) and moral condemnation and criticism of the industrial civilization, such as *A Blueprint for Survival* (20), those decades saw the mainstreaming of environmentalism. Green development can include measures such as using renewable energy sources, improving energy efficiency, reducing waste and pollution, preserving green spaces, and promoting public transportation and alternative modes of transportation that minimize carbon emissions (21).

In 1972, the United Nations conference was held in Stockholm, the first world conference to address the environment as a major issue (22). The Brundtland Commission, supported by the UN, defined sustainability as fulfilling current requirements without jeopardizing the needs of future generations in terms of development, marking the official beginning of the concept (23). At the Rio Earth Summit, it took center stage as the mainstream environmental movement's ethos and slogan (4). Its critics dismissed it as a trendy phrase to which everyone refers to; yet, nobody can define it (24). Some have questioned the promise of a new paradigm as mere green propaganda for business as usual (25). Others viewed it as a hegemonic "cover-up operation" designed to persuade and calm a populace concerned about the impact of economic growth (26). It is most peculiar that ecological concepts have been overridden so that, by the 2000s, sustainable development focuses almost exclusively on economic growth (25). The rise in environmental concerns is a significant factor that led to the emergence of green development (27). Sustainable development failed to address the growing environmental issues and the urgent need to mitigate the effects of climate change (28). Therefore, green development emerged as a new framework that prioritizes environmental protection and addresses the shortcomings of sustainable development (29). Despite the efforts of sustainable development, the world continues to face pressing environmental challenges such as pollution, loss of biodiversity, and climate change. Sustainable development discourse and projects have not been successful in achieving their goals. Green development has emerged as an alternative approach that provides a fresh perspective and solutions to the current environmental issues (17). Green development represents new approaches to environmental intervention, such as "a particular type of capital which must be measured, conserved, produced, and even accumulated" (30). The Global Green Growth Institute identifies green development as one of the key pillars of sustainable and inclusive economic development, defining it as a development way aimed at achieving eco-friendly and economic growth (31).

2.2. Green development under the Chinese context

Green development has become an important concept in China's development strategy (32). In recent years, China has taken significant steps toward reducing pollution, increasing the use of renewable energy, and promoting sustainable development (33).

The concept of green development was formally proposed at the Fifth Plenary Session of the 18th CPC Central Committee (34). In recent years, the green development research has received increasing attention and recognition. Scholars generally agree that the green development model has become the inevitable choice for China's future development, focusing on ecological conservation and transforming the industry through high-quality green development (35). According to some studies, China's green development is a more innovative and upgraded development model to achieve sustainable development by protecting the ecological environment under the constraints of ecological and environmental capacity (36). Green development places a greater emphasis on ecological priorities and requires more systematic, holistic, and coordinated linkages between economic, social, and natural systems (37). Green development is a sustainable approach to development that prioritizes ecological considerations (38). It recognizes that economic growth and social progress must be achieved in harmony with nature and requires a more systemic, holistic, and coordinated approach to achieve this balance. This means that green development aims to ensure that economic activities are carried out in ways that are environment friendly and do not degrade natural resources. Green development recognizes that human society is an integral part of nature and seeks to promote social progress and economic growth while preserving the integrity of natural systems (39). This requires a more systematic approach to planning and policymaking, which takes into account the interrelationships between economic, social, and natural systems. Therefore, it is necessary to examine green development based on more complex spatial and temporal conditions and specific contexts (40). China's green development goals are backed by a strict environmental conservation law (41) and the government has launched a series of action plans to combat air, water, and soil pollution (42).

2.3. Cultural heritage management

Studies of cultural heritage are receiving increasing international attention as a result of the longstanding efforts of the United Nations Organization (43). In transforming our world Agenda for sustainable development, reference is made to culture as a priority component of urban planning and strategies. It is worth noting that this is also mentioned in the New Urban

Agenda (44). "Tradition" has become a rare resource of time, valued, and turned into an "inheritance" (45). It seems to have evolved through a process generally sparked by the rediscovery of cultural values (46). The 17th UNESCO Conference in Paris focused on the serious problem of the destruction of cultural and natural heritage, developed a series of measures for its protection, interpreted cultural and natural heritage, and defined cultural objects, architectural complexes, and sites as cultural heritage (47).

In particular, in defining topographical areas as human works of outstanding universal value or type of nature and humanity in historical, esthetic, ethnographic, or anthropological terms (47). The International Committee on Archaeological Heritage Management outlines fundamental guidelines for the examination, upkeep, and conservation, as well as the reconstruction of architectural heritage based on inventories and broad assessments of the resources (48). It was determined that this Committee should include the correct long-term conservation and curation of all relevant records and collections and the preservation of monuments and places *in situ*. The idea of preserving the heritage in its native setting is violated by any transfer of heritage components to new locations (49). Ensuring cultural content and diversity, as emphasized in the Recommendation on the Safeguarding of UNESCO (50) and United Nations (51) issued by the UNESCO (52), the United Nations adopted the text of the Convention for the Safeguarding of Intangible Cultural Heritage (53). Two of those points for managing intangible cultural heritage are mentioned: (i) intangible Cultural Heritage Preservation and (ii) ensuring that intangible heritage is treated with respect by the communities, groups, and individuals involved.

The dynamic management that will be mentioned in the cultural heritage management process is closely related and both involve the management of resources in a dynamic and ever-changing environment (54). Dynamic management is the process of actively and continuously adapting and adjusting management strategies and practices in response to changes in the environment, market conditions, or other external factors. In the context of cultural heritage management, dynamic management involves adapting strategies and practices to ensure the preservation, protection, and promotion of cultural heritage resources under changing social, economic, and environmental conditions (55). Dynamic management is a crucial aspect of cultural heritage protection because it enables cultural heritage sites to adapt and evolve over time while preserving their significance and authenticity (56). Dynamic management is a crucial aspect of cultural heritage protection (57). By embracing this approach, cultural heritage sites can continue to evolve and adapt while preserving their significance and authenticity for future generations (57).

2.4. The relationship between the green development and cultural heritage

Green development and cultural heritage are two interrelated concepts that can have a significant impact on each other. Green development refers to the approach to economic growth that emphasizes sustainability and the use of renewable resources to meet the needs of the present generation without compromising on the ability of future generations to meet their own needs. Cultural heritage, on the other hand, refers to the collective identity of a community or society, which includes traditions, beliefs, customs, and artifacts that have been passed down from one generation to another. The relationship between the green development and cultural heritage can be understood in several ways.

Intangible cultural heritage has the quality of cultural diversity and is also an essential guarantee for sustainable development; cultural heritage management has become a universal aspiration and a common concern (53). The cultural heritage reflected in the World Heritage List is regularly localized in cities (58). Continuity and compatibility are the greatest demanding situations for heritage management, as the historic environments need to constantly break barriers in form and function (59). Although it is rare, a multidisciplinary study on the connection between cultural heritage management and green development has caught the interest of specialists (60–62). The preservation of cultural heritage can contribute to green development by promoting the use of sustainable practices and the protection of the environment. The cultural heritage has been dexterously preserved over the historical (63) phase of unprecedented and continuous green development (64), the importance of promoting knowledge about green development, and the potential for results by fusing the use of cultural heritage with its inherent values, which has been highlighted by the UNESCO World Heritage Center and related organizations (65, 66).

The most remarkable feature of the World Heritage Convention (67) is that it links the concepts of the conservation of nature and the conservation of cultural property and presents them in a single list. The Convention recognizes how humans interact with nature and the essential need to maintain a balance between the two. The Budapest Declaration (68) adopted stresses the need to ensure an appropriate and fair balance between conservation, sustainability, and development, so that world heritage can be protected to promote social and economic development and the quality of life in our communities (68). In addition, in 2005, the Operational Guidelines further recognized that world heritage sites could support ecologically and culturally sustainable uses (69).

Culture and cities are so closely linked that the 2030 Green Development Agenda incorporates culture (70). The Union of Cities and Local Government (UCLG) has also adopted the idea that culture has an irreplaceable role in urban development, aiming to fill the gap between cultural management and green development (71, 72). An integrated and shared global framework is still missing to provide practical and standardized guidelines to address the integration of these topics (73, 74). The Research model of this study is shown in Figure 1.

3. Methodology

3.1. Case study

Admittedly, the use of case studies in research implies that comprehensive and integrated problems can be addressed, and that research approach allowed the researcher to narrow down a complex and broad subject matter or phenomenon into manageable research issues (75). The researcher obtained a more in-depth analysis of the phenomenon by collecting both qualitative

and quantitative data sets about it (76). In a case study, the researcher collected a variety of data, including quantitative and qualitative information, from multiple sources such as interviews, observations, documents, and other relevant materials. The goal was to gain a comprehensive understanding of the case being studied and to identify patterns, themes, and insights that can help to explain and interpret the findings.

3.1.1. Cultural heritage of the Grand Canal (Hangzhou section)

Flowing for thousands of years, the Grand Canal is not only a "treasure of the world" but also the "lifeblood of the city" of Hangzhou (77). Since 2002, canal improvement and conservation have been listed as one of the top 10 construction projects in Hangzhou (78). The "Hangzhou Grand Canal Cultural Protection, Inheritance and Utilization and National Cultural Park Construction Plan" put forward specific requirements: focusing on the construction of four types of main functions: control and conservation areas, theme exhibition areas, cultural and tourism integration areas, and traditional utilization areas (79).

The Grand Canal (Hangzhou section) has 11 heritage site segments mainly concentrated in Gongshu District (78). Among them, six heritage sites are as follows: Gongchen Bridge (80), Guangji Bridge (81), Qiaoxi Historical District (82), Fengshan Water Gate Site (83), Fuyi Granary (84, 85), and Xixing Canal (86). Five sections of heritage rivers are (87) Hangzhou Pond (south section), Shangtang River (Hangzhou section), Middle River, Longshan River, and Hangzhou Section of Zhendong Canal (88) (see Table 1).

3.1.2. Policy support

The Zhejiang Provincial Government has proposed the "Five water cohabitation" concept (五水共治), which aims to improve Zhejiang Province's water environment comprehensively while promoting people's wellbeing (89). It is necessary to explain that "sewage treatment," "flood prevention," "drainage water," "water supply treatment," and "water conservation" (90) are all maintained by the Five Water Cohabitation, and Hangzhou has since implemented a number of policies to improve its aquatic environment. The "Planning Outline for Grand Canal Cultural Protection, Inheritance and Utilization," released in 2019 (91), clarified that it is necessary to build the main axis to drive the overall development and reshape the Grand Canal in accordance with the idea of protecting the cultural heritage of the canal, improving the water resources of the canal, building a green ecological corridor, and promoting cultural tourism (92). The government set up the necessary departments to thoroughly manage the Grand Canal Heritage and its tributaries, restore the river's shoreline and the surrounding environment, and create an ecologically sound continuous riverfront space (93). In 2020, the construction of the Grand Canal national parks was included in the 14th Five-Year Plan (94). Since then, it has moved into a new era of Grand Canal protection and inheritance. Based on the principle of culture-centeredness and priority of conservation, the plan set goals such as optimizing the system's structure, improving the local ecosystem, demonstrating cultural values, and strengthening the protection, demonstration, and utilization of the Grand Canal heritage (94). In 2021, "The Great Wall, the Grand Canal, and the Long March National Cultural Park construction and protection plans" (94), put forward specific requirements to strictly protect and manage all kinds of cultural relics and the surrounding environment, and protect the ecology and traditional culture (95).

TABLE 1 Some heritage elements of the Grand Canal (Hangzhou section).

Heritage elements		Basic information
Categories	Name	
River	Shangtang River (上塘河)	Formerly one of the sections of the Lingshui Road (陵水道) built around 210 B.C., it was the main channel at the southern end of the Grand Canal until the 14th century A.D. after the full length of the Grand Canal was opened in the 7th century A.D.
	Middle River (中河)	It was built in the Tang Dynasty and runs north-south through the middle of Hangzhou city, connecting Shangtang River (上塘河) in the north and Longshan River (龙山河) in the south and is now a city landscape road.
	Longshan River (龙山河)	It was first dug in the 10th century AD, connecting the Grand Canal with the Qiantang River and completing the Qiantang River transport port.
	Xixing Canal (西兴运河)	It was first dug in 307 AD. It became an important section of the East Zhejiang Canal.
Remains of hydraulic facilities	Guangji Bridge (广济桥)	Built in 1489 AD, the bridge is 78.7 meters long and is well preserved.
	Gongchen Bridge (拱宸桥)	Built in 1631 A.D., it is 98 m long and is well preserved.
Accessory remains	Fuyi Granary (富义仓)	It is an ancient urban public storage complex along the Grand Canal that is relatively well preserved. It was first built in 1880–1884 AD. Now the basic pattern still exists.
Related Heritage	Qiaoxi Historical District (桥西历史文化街区)	Located in Gongshu District, it is an urban residential area formed by relying on the geographical advantage of Gongchen Bridge as a major water and land transportation route. Now the pattern of the historical district is well preserved.

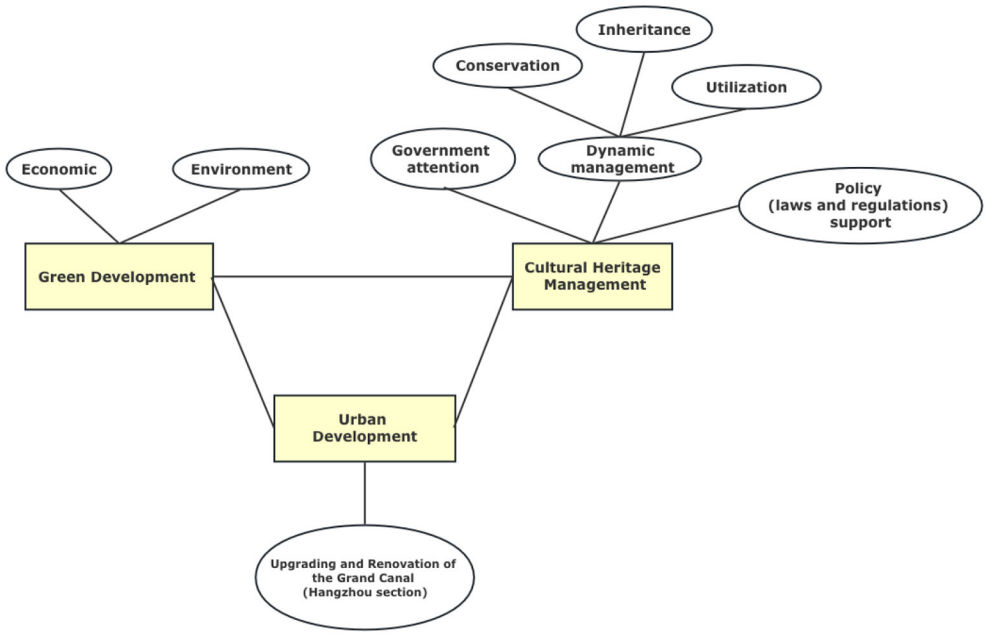

FIGURE 1
Research model.

3.2. Data collection

This research collected the Grand Canal (Hangzhou section) in China as research samples, and the data were obtained from trustworthy channels to ensure the credibility of the research. Given the integrity and continuity of panel data, the samples with serious missing data were not included. The data were primarily based on the Hangzhou Environmental and Ecological Bulletin. Statistical bulletins from 2014 to 2021 were referenced.

This research gathered data through regular work, including surveys and information on the preservation and renovation of the Grand Canal from local authorities, the media, and academic researchers, and also spent significant time correlating and analyzing these findings to draw more objective and credible conclusions to support the research arguments.

3.3. In-depth interview

The in-depth interview method is a qualitative research method. The researcher conducted personal and in-depth interviews with informants. During the interviews, research information was collected that cannot be captured in quantitative studies (96). In the process of interviewing, a similar interview outline was often used for a small group of individuals in a specific category, and then, the interviewer's pre-determined questions were revealed by summarizing the content of different interviewees' responses (97). Yet, there were many drawbacks to this method, such as the representativeness of the interviewees, the relevance of the interview outline, and whether the interviewees' personality characteristics influence the interviewer's judgment (96).

First, the researcher discovered 13 Informats who were qualified for the interview (or collecting public information from nearby residents interviewed). The interview information used in this study was also taken from public interview transcripts of studies of a similar type carried out by other media. These interviews were conducted with residents of the Grand Canal of various ages and genders to learn more about how their quality of life has changed over time, how satisfied and happy they feel in their community, and other related topics. The interview version also contrasted the alterations that took place before and after the Grand Canal renovation.

3.4. Research ethics

In this research, certain Informats may face potential risks, such as privacy and security issues. Consequently, Informats were anonymized in this study, and their real-life and online identities were guaranteed privacy. Informats were referred to as "Informat 1," "Informat 2," etc., during the data gathering process. All study Informats are anonymous. During the interviews, and to ensure reliability and critical distance, the researcher needs to maintain a neutral stance and not elicit answers from Informats.

4. Finding and discussion

The upgrading of the Grand Canal (Hangzhou section), a project that integrates green development and cultural heritage management, is discussed. The first one is about the emergence of green development. In this research, through the analysis of the data published in the Bulletin of Environment of Hangzhou,

although the rate of attaining the standard of the primary protected area of surface water sources for domestic drinking water was 100% in 1998, the rate of attaining the standard of the secondary protected area of surface water sources for domestic drinking water was only 25%, and the rate of attaining the standard of the agricultural water area and the general landscape requirement waters was 33.33% (see Figure 2). To eradicate the water pollution of the canal, Hangzhou has been carrying out large-scale interception and treatment of sewage and canal comprehensive improvement since 1998. However, there are still many sources of pollution along the canal that are directly discharged into the canal, seriously endangering the quality of the canal water bodies. Hence, residents living close to the Grand Canal (Hangzhou section) used to struggle with the poor quality of water.

Level II water quality by conventional purification treatment (such as flocculation, sedimentation, filtration, and disinfection) can be used for life after drinking.

Level III water quality after treatment can also be used for life after drinking.

Below level III water quality is poor, and it cannot be used as a source of drinking water.

> *"In the 80s, I often took a boat with my parents from Wulinmen and walked along the canal, the water was black and had a strong stench. Once the canal water, the most intuitive feeling is that the water is turbid and smelly."* - Informat 3
>
> *"Various factories along the canal discharged indiscriminately, "colorful" sewage is integrated into the Grand Canal, so the Grand Canal has become a stinky river that everyone dislikes. Before 2000 due to pollution, the water is basically extinct fish and shrimp, not to mention fishing, and even people can not get close to the front. The river stinks in the summer."* - Informat 5

The Grand Canal's water quality was indeed severely polluted before the year 2000, according to the confirmation from Informats who live nearby.

> *"In my childhood memories, the banks of the Grand Canal "scattered and dirty", sewage can be discharged directly into the canal, the river is dyed black. At that time, the canal and the ditch is no different, even in winter, also emits a pungent smell."* - Informat 12
>
> *"Black pollutants floated on the water of the canal, and since the 1950s, industrial and storage businesses have crowded its banks. In the 1980s, this also factories on both sides of the canal brought more industrial and domestic sewage to the hundreds of tributaries that feed into the canal."* - Informat 4

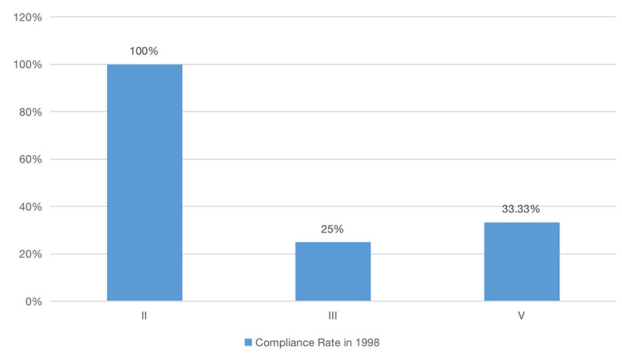

FIGURE 2
Water environment standard compliance rate in 1998.

This is corroborated by the remarks of interviewees 12 and 4. In the wave of economic development, the water quality of the Grand Canal has become more polluted, with a series of water pollution incidents and a deteriorating water environment, which has affected the production and life of local residents to varying degrees.

One of the main goals of the renovation project is to improve the canal's water quality. Over the years, the canal has suffered from pollution caused by industrial and agricultural activities in the region. The Hangzhou government has implemented a number of measures to combat this pollution, such as limiting the discharge of wastewater into the canal and planting vegetation along its banks to help filter out pollutants. By comparing the water quality data of Hangzhou in the past 8 years, it was found that Hangzhou's water quality compliance rate continues to improve every year. The compliance rate increased by 19.1% from 2014 to 2021, and achieving or better than the III standard has been maintained at 100% for the past two years, which is 25.5% higher than the 74.5% in 2014 (refer to Figure 3). Positive environmental impact benefits everybody by reducing pollution and protecting aquatic ecology.

> *"In recent years, it is obvious that the ecological quality around the canal has improved, and the nearby greenery feels all the greener, and it feels like the quality of life has improved."* - Informat 9

People's wellbeing and green development are intricately linked as the health of the environment and the wellbeing of individuals are interdependent. Green development can help to protect the environment and ensure that natural resources are conserved for future generations. This is particularly important in the face of climate change, which poses a significant threat to both the environment and human wellbeing. By prioritizing sustainable practices and reducing our impact on the environment, we can create a healthier, more equitable, and sustainable future for all.

The local government further promoted the comprehensive protection projects of the Grand Canal. For example, the renovation of Old Residential Areas, old industrial plant reformation, and the renovation of urban-village, demolishing the illegal building (80), "Five-water Symbiosis" strategic project, "Sewage treatment," the coordination of the relocation of highly polluting enterprises away from the banks of the Grand Canal, and the strict prohibition of urban construction and industrial development on the large-scale transformation of the natural landscape of the Grand Canal.

The rate of meeting the criteria continues to increase each year, according to a comparison of Hangzhou Canal's water quality data during the past 5 years. The chart shows that, from 2017 to 2021, achieving or better than the III standard has been maintained at 100%, an increase of 33.3% from 2017 to

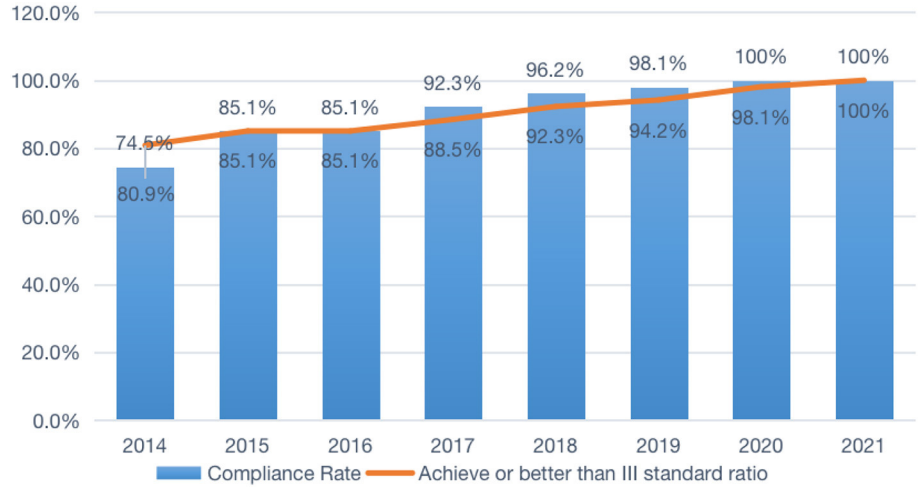

FIGURE 3
The water environment-related indicators of the Hangzhou city between 2014 and 2021.

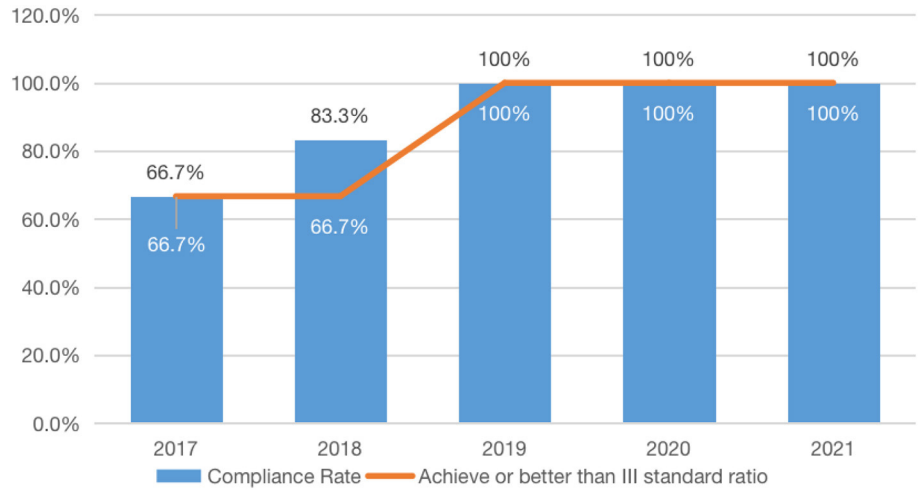

FIGURE 4
The water environment-related indicators of the Grand Canal (Hangzhou section) between 2017 and 2021.

2021. Especially in the past 3 years, the water quality condition of the canal has continued to be excellently maintained at 100%, which has greatly changed the living space, production space, and ecological environment of the people, and their sense of wellbeing has been continuously improving (refer to Figure 4).

> *"The clear water of the canal flowed from Gongchen Bridge, and rows of trees fell in golden color on the canal embankment road. The forest is full of color in autumn, and in summer, the flowers bloom not far from Xiaohe Park. I was able to catch such beautiful scenery."* - Informat 12

The second is the protection, inheritance, and utilization of the Grand Canal (Hangzhou section) combined with cultural heritage and green development. For example, since the end of the last century, Hangzhou has entered a phase of rapid development, and many old factory buildings that have lost their productive functions and economic benefits have occupied numerous land resources. The core of the entire protection and improvement activity along the canal was centered on the remains of historic industry structures. These old industries, which are closely linked to the Grand Canal and have experienced the contemporary industrial growth of Hangzhou and carried the memories of a generation, are an essential component of the Grand Canal's cultural history and must be protected. In response to this urban issue, the government proposed to "give the river back to the people" to enhance and protect development around the canal. Additionally, green corridor components should be added as essential urban walking and natural infrastructure. These plots of old factory buildings should also be used and given cultural functions adapted to contemporary urban life.

> *"I wander along the banks of the Grand Canal, and now I can no longer hear the roar of factory machinery or see the busy workers, but see the museum with an intense cultural atmosphere, which injects vitality and vigor into the old factory buildings. It feels like the old factory has completed its magnificent transformation and become a new cultural card along the canal."* - Informat 10

Government efforts are also being made to preserve the cultural and historical significance of the canal. The Hangzhou government has invested in the restoration of historical sites along the canal, such as temples and bridges, as well as in improving the infrastructure and facilities for visitors. The renovation project also includes the construction of new pedestrian and cycling paths, which will provide a more accessible and environment-friendly way for people to explore the canal and its surrounding areas.

> *"Trading the scenery with moving steps"*. This is the feeling raised by Informat 6. "*Living around the Gongshu section of the Grand Canal, she walks along the river every day after dinner." 21 museums, 5 historical districts, small river parks, riverside green space...living here makes me feel blessed.*

The relationship between the old factories and the canals needs to be reshaped to activate this industrial heritage. In the past, fences separated the old factory buildings from the canals. The first step in the transformation was to remove the walls and break the boundaries. Canal industrial heritage has its unique image and spatial characteristics. It involved the preservation of chimneys, tall windows, and other traditional manufacturing building features; retaining the remaining tanks, pipes, hangers, and other structures in the site, and integration of original contemporary landscape design into the new architectural and site context.

> *"I reside close to Xiaohe Park, which was formerly an oil depot as you can see. The oil depot pollutes the land and surrounding water sources. But since the oil depot was completely shut down in 2019, it has been transformed into Xiaohe Park with a beautiful environment. The quality of life has greatly improved."* - Informat 11
>
> *"The one I can think of the most is the Hangzhou Iron & Steel Factory, which was shut down after over 60 years of operation and has since been converted into a section of the Grand Canal National Cultural Park. It has retained numerous significant remains with great industrial features. This news made me incredibly delighted from the bottom of my heart."* - Informat 13

Third, Hay (98) defines the establishment of green corridors as "green landscape chains connecting open places." These canals with natural elements integrated ecology, culture, and recreation. Ahern (99) defines corridors as planned, designed, and managed linear network systems with ecological, cultural, recreational, and esthetic functions and as a sustainable land planning tool. The concept of heritage corridors was first introduced to China by Zhifang and Peng (100) a new approach to regional preservation of linear cultural heritage, often with a specific economic center, thriving tourism, modifying old buildings, environmental improvements, and entertainment. It is a new type of green corridor that integrates ecological, economic, historical, and cultural functions developed from green corridors that focus on ecological functions combined with heritage conservation. For example, the green corridor construction of the canal is more multifunctional through walking trails and public spaces all through the line, adding comprehensive service facilities.

> *"Cycling along the canal a few years ago, it was evident that the greenway system could have been better. Now, the cycling path has become smooth. The greenery on both sides of the canal is doing well; I still remember that in autumn, cycling along the canal, the fragrance of osmanthus drifted."* - Informat 7

When asked these questions, whether it is Xiaohe Park or it is the Hangzhou Iron & Steel Factory, these sites can be considered as epitomizing the cultural heritage management and green development of the Grand Canal. Although the sample is small, it gives a side view of the residents' future direction for canal city, and one of their expectations is the integration of green and culture.

> *"I don't know about other places, but take Hangzhou as an example. At the beginning of the reform and opening up, the canal along the convenient transportation, many industries are also located nearby, the economy is relatively developed, and foreign exchanges are also convenient. But the industrial development of that time is serious environmental pollution. But now, the economy has been transformed, relying on the resources of the Grand Canal, and many cultural and creative-related or innovative stores have been opened here. And also often co-organize meaningful activities with the museum"* – Informat 11
>
> *"The canal city has formed ecological landscape belts and cultural tourism resource belts on both sides, and emerging industries such as cultural creativity and technological design have sprung up. You can see a lot of unique coffee houses, bookstores, and tea bars opened along the canal. Many people will come here on weekends. And the surrounding area relies on the industrial heritage to carry out many special activities, such as various exhibitions. These activities add a youthful vitality to the old canal."* - Informat 1

The construction and renovation of the Grand Canal's water quality and environment have resulted in several benefits, including the following: Livelier banks: Improved water quality and a healthier living environment have led to more vibrant and lively canal banks. Residents and visitors alike can enjoy walks, cycling, and other outdoor activities along the canal, which has become a popular destination for recreation and tourism. More beautiful communities: The restoration and improvement of the Grand Canal have also contributed to the beautification of the surrounding communities. The canal banks are now adorned with flowers, trees, and other greenery, creating a more visually appealing and attractive environment. Better quality of life: Access to clean and safe water has had a significant impact on residents' quality of life.

Improved water quality means residents can enjoy better health. Healthier living environment: The improved water quality and environmental conditions of the Grand Canal have also had a positive impact on the wider ecosystem. Fish and other aquatic life have returned to the canal, and the water quality has improved, reducing the risk of waterborne illnesses and pollution-related health problems. In conclusion, all Informats answered that the construction and renovation of the Grand Canal's water quality and environment have had far-reaching benefits, which made the banks of the Grand Canal more lively, their communities more beautiful, their lives replete with more quality, and their living environment more healthy.

5. Conclusion

"Green" has become a key component of the current and future urban development, and the same applies to a city with a rich cultural history. By combining the cultural heritage of the Grand Canal (Hangzhou section), this study identifies a successful example of the integration of the Grand Canal's cultural heritage conservation strategies into urban green development. Simultaneously, the surrounding citizens' living conditions and quality of life have improved as a result of the coordinated management of cultural heritage and green development in addition to enhancing their sense of wellbeing and satisfaction with the city.

5.1. Theoretical contributions

Green development and cultural heritage management are two important areas of research that have received significant attention in recent years. Theoretical contributions in these fields have played a crucial role in shaping our understanding of the complex relationship between economic development, cultural heritage preservation, and environmental sustainability.

Green development is an approach to economic development that emphasizes sustainability and environmental protection. The theoretical foundations of green development can be traced back to the concept of sustainable development, which was first introduced in the 1987 Brundtland Report. The aforementioned report defined sustainable development as "development that meets the needs of the present without compromising the ability of future generations to meet their own needs." Since then, a large body of literature has emerged that explores the various dimensions of green development, including sustainable economics, green infrastructure, and sustainable urban planning.

Cultural heritage management is concerned with government attention, dynamic management, and policy support. Cultural heritage can include everything from historic buildings and archeological sites to traditional knowledge and cultural practices. The theoretical foundations of cultural heritage management can be traced back to the field of cultural anthropology, which has long been concerned with the study of cultural practices and traditions. Another important theoretical contribution is in the field of dynamic management. This concept emphasizes the importance of designing management strategies that enhance the resilience of cultural heritage resources, allowing them to withstand and recover from the impacts of environmental and social change.

5.2. Practical significance

The most striking aspect of this research is the innovative integration of traditional urban cultural heritage management, as an intrinsic factor in the green development of a city, into the contemporary concept of green development. By analyzing the conservation and upgrading of the Grand Canal (Hangzhou section), the macroscopic problem became concretized and the important value of the conservation and upgrading of historical and cultural heritage, in harmony with the green development of the urban, is argued.

Because of the Grand Canal's large spatial and temporal span, the diverse types of cultural heritage, the overlapping and interlocking heritage resources of different periods and forms, and the conservation requirements are currently more complex than those of general heritage. Some intangible cultural heritage inheritance vitality still needs to be improved. However, in some cases, a conflict exists between the conservation and utilization of natural resources involved in various types of culture and the green development of the Grand Canal.

Scholars have raised a number of concerns about the relationship between cultural heritage preservation and green development. Some of the key concerns include the following: Balancing economic development and heritage preservation: One of the main concerns is how to balance the need for economic development with the preservation of cultural heritage. Many scholars are worried that economic development can lead to the destruction of cultural heritage sites and practices. Another concern is that cultural heritage preservation may not receive adequate funding. Scholars are worried that, without sufficient resources, heritage sites may not be adequately protected and preserved. Scholars are concerned that heritage preservation efforts may not involve local communities enough. They are worried that, without the involvement and participation of local communities, preservation efforts may be less effective and may not reflect the cultural values and priorities of the people who live in the area.

Of course, from the information materials observed and gathered by the author, the local government of Hangzhou City and grassroots governments such as Gongshu District are comprehensively implementing the requirements of the 20th CPC National Congress, especially the new development concept proposed by General Secretary Xi Jinping, promoting the protection and utilization of the Grand Canal cultural heritage, and encouraging the harmonious development of humans and nature (6). Especially in conjunction with the Asian Games to be held in 2023, more conservation projects have been arranged to make cultural heritage protection and green development more coordinated and sustainable so that the local residents can get more benefits from them and have a stronger sense of access and happiness. Combining green development and urban cultural heritage can be a challenging task. It is important to preserve the existing urban cultural heritage to maintain a sense of history and place, and a balance needs to be struck between preserving the past

and preparing for the future. It is important to recognize the unique history and character of each community or city and work to integrate green development in a way that enhances these qualities.

Specifically, the sample size used in the article's research, which implies that the results or conclusions are drawn from the data, may not be as reliable or generalizable as they could be with research done with a larger sample size. This limitation could impact the credibility and validity of the research presented in the article. For instance, a small sample size might not adequately represent the population being studied, leading to a potential bias and a lack of precision in the results. Additionally, it may limit the ability to draw meaningful and robust conclusions from the data, which could impact the usefulness of the article for readers.

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.

Author contributions

Conceptualization, formal analysis, methodology, resources, and writing: YX. The author has read and agreed to the published version of the manuscript.

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Conflict of interest

The author declares that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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The influencing factors of elder-friendly public open spaces promoting older adults' health in deprived urban neighborhoods: Partial Least Square Structural Equation Modeling approach

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Background: Public open spaces (POSs) is considered a feature of the built environment that is important for physical, mental, and social health during life and contributes to active aging. Hence, policymakers, practitioners, and academics have recently focused on indicators of elder-friendly environments, particularly in developing countries.

Objective: This study aimed to examine the attributes of POSs and socio-demographic status that positively influence older people's health in Tehran's deprived neighborhoods using a pathway model.

Methods: We employed a pathway model to explore the relationships between place function, place preferences, and process in the environment as the perceived (subjective) positive features of POSs associated with older adults' health, compared to the objective attributes of POSs. We also included personal characteristics, including physical, mental, and social dimensions, to explore how these factors are related to the health of older adults. To assess the subjective perception of POSs attributes, 420 older adults were asked to complete Elder-Friendly Urban Spaces Questionnaire (EFUSQ) from April 2018 to September 2018 in the 10th District of Tehran. We used the SF-12 questionnaire and "The self-Rated Social Health of Iranians Questionnaire to measure older people's physical and mental health and elder social health." Geographical Information System (GIS) measures (Street connectivity, Residential density, Land use mix, Housing quality) were derived as objective measures of neighborhood features.

Results: According to our findings, the personal aspect, socio-demographic status (such as Gender, Marital status, Education, Occupation as well as Frequency of being present in POSs), place preferences (Security, Fear of Falling, Way Finding and Perceived Aesthetics), and process in the environment's latent (Social Environment, Cultural Environment, Place Attachment, and Life Satisfaction) constructs collectively influenced the elders' health.

Conclusion: We found positive associations between Place preference, Process-in-environment, and personal health-related factors to elders' health (social, mental, and physical). The path model presented in the study could be guided in

future research in this area and inform the development of evidence-based urban planning and design interventions for improve older adults health and social functioning and quality of life.

KEYWORDS

public open space (POS), elderly health, perceived attributes, PLS-SEM, neighborhoods

Introduction

The number of people above 65, i.e., older adults, will double by 2050 (1). Physiologically speaking, aging results from accumulated molecular and cellular damage, gradually decreasing physical and mental capacities and increasing chronic diseases (2). There is growing evidence to support late-life living environments as well as associations between the features of the outdoor environment and health outcomes (3–5). Well-maintained public open spaces (POSs) can enhance older adults' physical and mental health and well-being (6–8). Changes in mortality, physical function, disease prevalence, and mental health status in different environments can support this relationship (9). With other attributes of the building, say, walkability, and public transport infrastructure, POSs bring about various benefits, such as promoting physical activity (7, 10) and creating social cohesion in neighborhoods ((10, 11); (7)). Older adults' health depends on some elements, including lifestyle, genetic predisposition, social relationships, and environment (7).

Besides, the research found an association between POSs and chronic health conditions like obesity (4, 7), cardiovascular disease (12), diabetes (7, 12), respiratory health (13), and mental health (e.g., stress, anxiety, depression, and attention) deficit disorders (7, 12). In line with this body of research, POS in this study refers to local green spaces in neighborhoods.

Studies of older adults have found that some characteristics of POSs are likely to increase walking activities in residential neighborhoods (14–16). These characteristics include walking for transportation (17), recreational physical activity (15) in local streets (18), and urban parks (19, 20), including amenities like shade structures, toilets, trees and plants, and well-paved surfaces and like to experience minimal traffic and seat along walkways (1), "trees/plant" (20) and park seating (21).

The provision of appropriate POSs is a major social determinant of health contributing to an area's livability, particularly in deprived urban neighborhoods (22), regarded as "safe, secure, attractive, socially cohesive and inclusive, and environmentally sustainable; with affordable and diverse housing linked to employment, education, public open space, local shops, health and community services, and leisure and cultural opportunities; *via* convenient public transport, walking and cycling infrastructure" (23).

To examine the impact of individual and environmental factors on the presence of older adults in POSs and on their health outcomes, our study adopts such an ecological perspective (24), which includes three potential mechanisms of older adults' health as physical activity in outdoor spaces, social interaction, and contact with nature (25).

As Iranian society's traditional structure disapproves of sending senior people to nursing homes, aging in place is the appropriate solution to help older adults in Iran remain physically and mentally healthy. Creating elder-friendly POSs can help them live active and healthy life and experience an acceptable quality of life (26). Although many researchers have already studied the relationship between POSs and older adults' health, there is still a shortage of robust evidence to support contemporary policy demands in an aging society (12). Besides, the health status of older adults in the POSs of neighborhood' was addressed internationally (7, 23), but there is a significant gap in Iran's quantitative research (27, 28). A 2015 report by Tehran Municipality states that although Iran is a group of 33 countries involved in moving toward age-friendly cities, the government is not equipped with the necessary infrastructure (29–31). The collected data show that theoretical findings have led to neither a deep understanding of the local preferences of older adults in Iran nor practical guidelines for designing and developing age-friendly POSs. With this in mind, this study aims to explore the relationship between self-related health and features of POSs to enhance the presence of the elderly in POSs in the deprived neighborhoods of Tehran, Iran.

Materials and methods

Study site

This study was carried out in public spaces (POSs), including parks, squares, and neighborhood hangouts, in Tehran's 10th district. Tehran's 10th district has relatively the highest population among Tehran's regions and the highest number of older adults. It has a relatively low area of residential use; therefore, most older adults use public spaces in their neighborhoods (32). Of 287,476 people in the 10th district of Tehran, more than 10 percent are above 60 years old (33).

Study design

This cross-sectional study was conducted on 420 older people who regularly used public outdoor spaces (POSs) in Tehran's 10th district neighborhoods over 4 months during Spring/Summer in 2018. Participants were asked to complete three questionnaires, the SF-12 questionnaire, the Self-Rated Social Health of Iranians Questionnaire, and an elder-friendly urban spaces questionnaire (EFUSQ), after obtaining their written consent assisted by research assistants. Trained research assistants facilitated this through face-to-face interviews. They all received a three-hour training which covered how to introduce questionnaires and administer interviews to ensure standardized facilitation for accuracy, completeness, and reliability. Data collection for each participant took about 20–30 min. The Iran University of Medical Sciences (IUMS) granted ethical approval, and

all participants signed informed consent before participating in this research.

Participants

From April through September 2018, participants were chosen using a purposeful (non-random) sampling technique. To be considered, the individuals had to frequent the open areas (parks, squares, and streets) in the District 10 neighborhoods of Tehran at least three times each week. Those with severe physical disabilities who could not use POSs and had communication problems were not considered for this study.

Measurements

The subjective measure of the neighborhood's perceived environment, which we used here, was measured through an adapted version of the Elder-Friendly Urban Spaces Questionnaire (EFUSQ) (28). The questionnaire consists of 50 items divided into three parts in terms of environmental dimensions plus one piece which is related to socio-demographic status:

1. Place functions (amenities, density, safety, traffic, objective aesthetics, urban landscape, comfort, and environmental cleanness).
2. Place preferences (PP) (crime security, fear of falling, fear of losing, and image).
3. Process in environments (cultural environment, social environment, life satisfaction, and sense of belonging).
4. Socio-demographic statuses like gender, age, marital status, and occupation.

The objective measures of the environment of neighborhoods were based on the variables of the Geographical Information System (GIS), which were measured in Euclidean or straight-line distances buffer within 500 m of the centroid of a neighborhood using ArcGIS® version 10 (34).

1. Street connectivity: Based on the number of real intersections in an area, street connectivity is defined by the number of links between streets divided by the number of street nodes in the buffer area.
2. Residential density: The number of dwelling units was divided by the residential land area in this region to obtain this measure.
3. Land use mix: Land use mix is the distribution of development among five types of use (i.e., residential, commercial, recreational, industrial, and others).
4. Housing quality: This shows whether or not a person's home is located inside a deteriorated neighborhood.
5. Frequency of POS uses: This measure refers to the number of visits older person's weekly make to POSs (never, once a week, twice a week, more than three times a week).

In the Self-reported Quality of Life (SF-12), the participant's self-rated health was reported as 'excellent,' 'very good,' 'good,' 'poor,' or 'very poor.' Physical and mental quality of life was recorded using 12 questions from the simplified Iranian version of Medical Outcomes Study Short Form 12 (SF-12 v2) Health Survey. The survey has already been validated in Iranian populations and is widely used to evaluate the general population's health (35). According to Montazeri et al. (35), the evaluation of physical health requires a combination of four subscales [general health (one item), physical functioning (two items), physical role (two items), and bodily pain (one item)]. Evaluation of mental health, too, requires a combination of four subscales [vitality (one item), social functioning (one item), emotional role (two items), and mental health (two items)]. These physical and mental health component scores were calculated using normative subscale scores for the Iranian population (35).

Also, we used the "Self-Rated Social Health of Iranians Questionnaire," which consists of 33 items to evaluate social health (36). The total score was the sum of all 33 items (minimum one and maximum 5 points/item), and the total score lies between 33 and 165, with higher scores indicating better self-reported social health. This scale comprises three domains; community, family, friends, and relatives, with 19, 6, and 8 items for each. Family refers to all household members, and "friends and relatives" refer to those with whom an individual has a close relationship. Other social activities/communications are included under the "community domain." The psychometric parameters of this scale were verified in the context of the Iranian population (36).

Data analysis

We applied Partial Least Square Structural Equation Modeling (PLS-SEM) to understand better the influencing factors of the health of older people in POSs' attributes-regarding social, mental, and physical domains of health-and to develop a conceptual model. PLS-SEM is a causal predictive analysis of both formative and reflective variables (37). It is a common multivariate analysis method for calculating variance-based structural equation models and is widely applied in social sciences (38). Moreover, it also provides an opportunity to resolve the multi-dimensional causal relationships that are otherwise difficult to explore. PLS-SEM can be used to assess the path coefficient (or connection strengths) as parameters of the model estimating effective connectivity. Furthermore, PLS-SEM also handles data distribution using the bootstrapping technique to calculate the significance value for coefficients of the model (pathway).

The proposed model was analyzed using a two-step process. First, the model deals with latent variables (measurement models) that define the association between latent indicators and their manifest variables. Second, an SEM describes the associations between the latent variables. This model explains the relationships between the latent variables and their related manifest variables. A total of 27 factors derived from the literature were recognized as the observed variables and categorized into five groups called exogenous latent constructs. They included the place function factor, place preference factor, process-in-environment factor, the factor related to objective attributes of the outdoor environment, and personal factor.

Therefore, the endogenous latent variable (an older person's health) consisted of five exogenous (observed) variables. Figure 1 shows the conceptual model that illustrates the relationships between endogenous latent constructs and exogenous latent constructs.

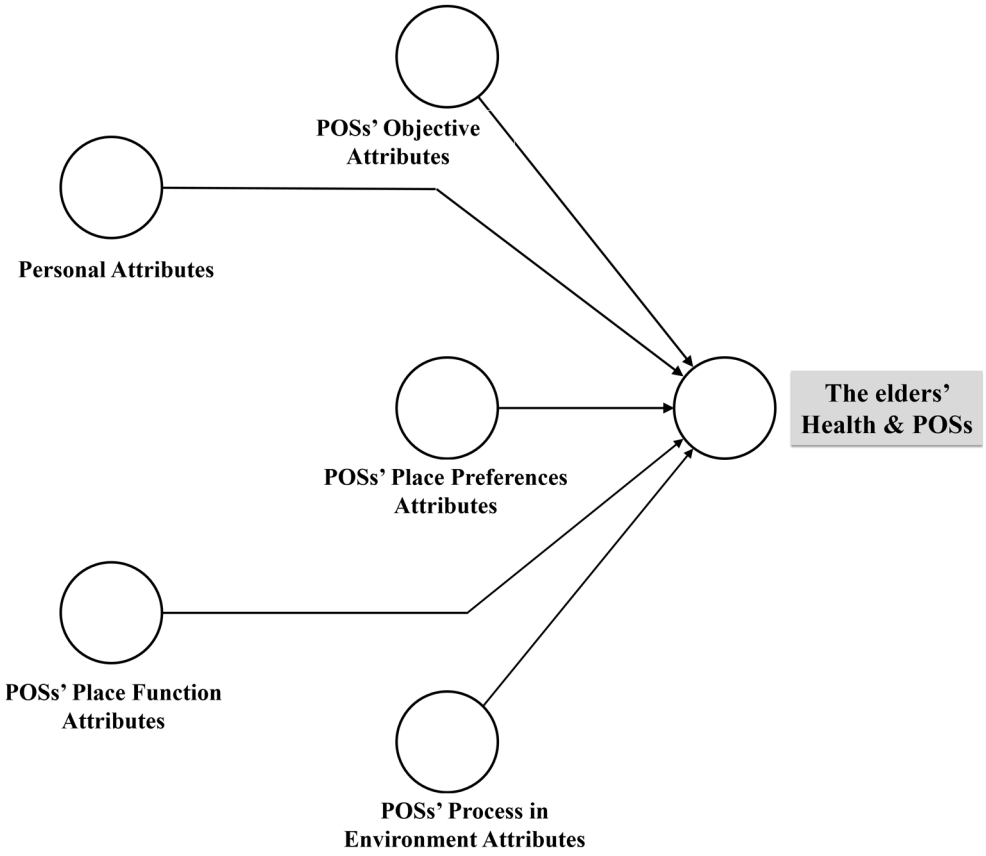

FIGURE 1
The proposed conceptual framework.

Therefore, our overarching hypothesis is that five primary constructs influence the health of older adults assessed using physical and mental HRQoL dimensions and social health.

Our research hypotheses are as follows:

> *Hypothesis 1 (H1)*. The place function factor (PF) significantly and positively affects older adults' health.
>
> *Hypothesis 2 (H2)*. The place preference factor (PP) significantly and positively affects older adults' health.
>
> *Hypothesis 3 (H3)*. The process-in-environment factor (PE) significantly and positively affects older adults' health.
>
> *Hypothesis 4 (H4)*. The factor related to the outdoor environment objective attributes (OB) significantly and positively affects older adults' health.
>
> *Hypothesis 5 (H5)*. Personal factor (PR) significantly and positively affects older adults' health.

To validate the model, the standardized root mean square residual (SRMR) was employed as an index used to show the average of standardized residuals between the observed and the hypothesized covariance matrices (39). SRMR is counted as a measure of the estimated model fit; if SRMR = < 0.08, the study model can be claimed to have a good fit (40), with lower SRMR values indicating a better fit.

Results

Baseline data

Data were drawn from the survey conducted on 420 older residents of district 10, Tehran municipality. The study participants' mean (SD) age was 76.3 ± 9.2 years, 61.3% males, 73.5% married, and 27.2% without a high-school diploma (Table 1). Twenty participants were excluded from the leading models due to high missing data levels.

The simulation to calculate the impact of the observed variables and their latent constructs on the health of older adults was analyzed using smart-PLS version 3.2.7.

Evaluation of the outer measurement model

The outer measurement model calculates the internal consistency of observed variables (measured by the questionnaire) and their reliability, validity, and unobserved variables (41). Evaluations of

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TABLE 1 Descriptive characteristics of the study participants (n=420).

	Variables	*N* (420)	Percentage
Gender	Men	260	(62%)
	Women	160	(38%)
Marital status	Single	40	(10%)
	Widow	90	(30%)
	Married	290	(60%)
Education	Illiterate / Lower than high school	198	(47%)
	High school	156	(37%)
	Academic	66	(16%)
Occupation	Employed	50	(12%)
	Housewife	122	(29%)
	Retired	248	(59%)
Frequency of being present in POS	Never or once a week	150	(36%)
	Twice a week	150	(36%)
	Three times a week or more	120	(28%)

consistency are based on a single observed variable and construct reliability tests, while validity is assessed by convergent and discriminant validity (38).

A single observed variable reliability is supposed to describe the variance of an individual observed compared to an unobserved variable by assessing the standardized outer loadings of the observed variables (42). An outer loading of 0.7 or greater means that the observed variables are considered exceedingly acceptable (38), whereas a value of less than 0.7 should be discarded (43). In this study, the cut-off value accepted for the outer loading was 0.7, and 0.4 or greater values are acceptable for exploratory analyses. As listed in Table 2, the outer loadings range between 0.191 and 0.823. Cronbach's alpha and Composite Reliability (CR) values were used to evaluate internal consistency in construct reliability.

Compared with Cronbach's alpha, CR is supposed to evaluate internal consistency better because it preserves the observed variables' standardized loadings (44). In our work, however, Cronbach's alpha and the CR value produced the same results. As seen in Table 2, Cronbach's alpha was not greater than 0.7, whereas CR for the latent constructs 1, 2, and 3 was more significant than 0.70. Thus, the scales were confirmed as reasonably reliable, indicating that all latent constructs values were more significant than the minimum threshold level of 0.70. The Average Variance Extracted (AVE) of each latent

TABLE 2 Construct reliability and validity.

Main constructs	Items	Outer loadings	Cronbach's alpha	CR	AVE
Place function (PF) factor	PF1: Density	−0.389	0.526	0.722	0.418
	PF2: Amenities	0.633			
	Pf3: Safety	0.556			
	PF4: Urban landscape	0.728			
	PF5: Comfort	0.816			
	PF6: Environmental cleanness	0.670			
	PF7: Aesthetics	0.680			
Place preference (PP) factor	PP1: Security	0.739	0.494	0.704	0.399
	PP2: Fear of falling down	0.859			
	PP3: Way finding	0.383			
	PP4: Perceived aesthetics	0.409			
Process-in-environment (PE) factor	PE1: Social environment	0.621	0.493	0.759	0.347
	PE2: Cultural environment	0.263			
	PE3: Place attachment	0.680			
	PE4: Life satisfaction	0.556			
The factor related to place objective attributes (OB)	OB1: Residential density	0.454	−0.088	0.188	0.235
	OB 2: Land use mix	0.653			
	OB 3: Street connectivity	0.235			
	OB 4: Housing quality	−0.501			
Personal-related factor (PR)	PR1: Age	0.459	0.040	0.223	0.226
	PR2: Education	0.509			
	PR3: Marital status (Married)	0.680			
	PR4: Frequency of visits	0.402			
	PR5: Gender (Female)	−0.191			

TABLE 3 Fornell–Larcker criterion test.

Personal-related factor	Objective related factor	Process-in-environment factor	Place preference factor	Place function related factor	
				0.646	Place function related factor
			0.632	0.649	Place preference related factor
		0.589	0.379	0.497	Process-in-environment related factor
	0.484	−0.050	0.005	−0.032	Objective related factor
0.475	−0.197	−0.005	0.013	0.052	Personal-related related factor

construct was calculated to verify the variables convergent validity (44). The latent constructs in the model should take the lowest 50% of the observed variable variance. This shows that AVE's value for all the constructs should be greater than 0.5 (45). To achieve discriminant validity, the square root of AVE for each latent variable should be greater than the correlations among the latent variables. So, convergent validity was confirmed for this study model. These results confirmed the convergent validity and the internal consistency of this model.

The next step was to measure the discriminant validity of the latent constructs. The notion of discriminant validity indicates that the manifest variable in any construct should be distinguished from other constructs in the path model in which the cross-loading value in the latent variable is higher than in any other construct (46). We used the Fornell and Larcker criterion and cross-loadings to assess the discriminant validity (44). The proposed standard is that a construct should not indicate the same variance as any other construct more significant than its AVE value (46).

Table 3 lists the Fornell and Larcker criterion test results in which the squared correlations were compared with correlations from other latent constructs. As shown in this table, all correlations were smaller than the squared root of average variance exerted along the diagonals, which implies adequate discriminant validity. All constructs observed variables correspond to the given latent variable, confirming the model's discriminant validity. As a result of proper reliability, convergent validity, and discriminant validity, the suggested conceptual model proved relatively acceptable.

Evaluation of the inner structural model

The validity and reliability of the measurement model were confirmed in this analysis through Inner Structural Model. This entailed an examination of the predictive relevancy of the model and the relationships between the constructs. The primary standards for assessing the inner structural model are the coefficient of determination (R^2), path coefficient (β value), and T-statistic.

Measuring the value of R^2

The coefficient of determination measures the overall effect and variance defined in the endogenous construct for the structural equation model. Therefore, it is a measure of the predictive accuracy of the model. In our study, the inner path model's value was 0.490 for the quality endogenous latent construct, meaning the five independent constructs can explain 49% of older adults' health variance. According to Henseler et al. (47) and Hair et al. (46), an R^2 value of 0.75 is considered substantial, 0.50 as moderate, and 0.26 as weak. Based on this, the R^2 value in this study was moderate.

Estimation of path coefficients (β) and T-statistics

The regression analysis showed a similarity between the PLS path coefficients and the standardized β coefficient. The significance of the hypothesis was examined using the β value. The β denoted the dependent construct's expected variation for a unit variation in the independent construct(s). For every path in the hypothesized model, we calculated the β values. A more excellent β value meant a more substantial effect on the endogenous latent construct. We verified the significant level of β value using the T-statistics test. We used the bootstrapping procedure to assess the hypothesis's significance (48). The importance of the path coefficient and T-statistics values was tested through a bootstrapping method using 5,000 subsamples. Table 4 summarizes our results.

As to H1, the PF factor ($\beta = 0.053$, $T = 838$, $p > 0.05$) did not significantly and positively influence older adults' health. This was also the case for the OB factor ($\beta = -0.068$, $T = 0.875$, $p > 0.05$). Therefore, this model could not support H4. As predicted, the findings in Table 4 show that the PR factor significantly influenced health ($\beta = 0.224$, $T = 3.194$, $p = 0.014$). Thus, H5 was robustly supported. Concerning the direct and positive effect of the PE factor on health (H3), the results in Table 4 confirm that this factor highly significantly affects the health status in older adults ($\beta = 0.218$, $T = 4.715$, $p < 0.001$), thereby confirming H3. The influence of place preferences (PP factor) on health in older adults was significant and positive ($\beta = 0.180$, $T = 3.196$, $p = 0.01$), which supports H2.

TABLE 4 Path coefficient and T-statistics.

Hypothesized path	Standardized beta	*T*-values	*p*-values	Supported
Place function related factor – > older adults' health	0.053	0.838	0.402	_
Place preference related factor – > older adults' health	0.180	3.196	0.01	✓
Process-in-environment related factor – > older adults' health	0.218	4.715	0.01	✓
Place objective attributes related factor – > older adults' health	−0.068	0.875	0.382	_
PR related factor – > older adults' health	0.224	3.196	0.014	✓

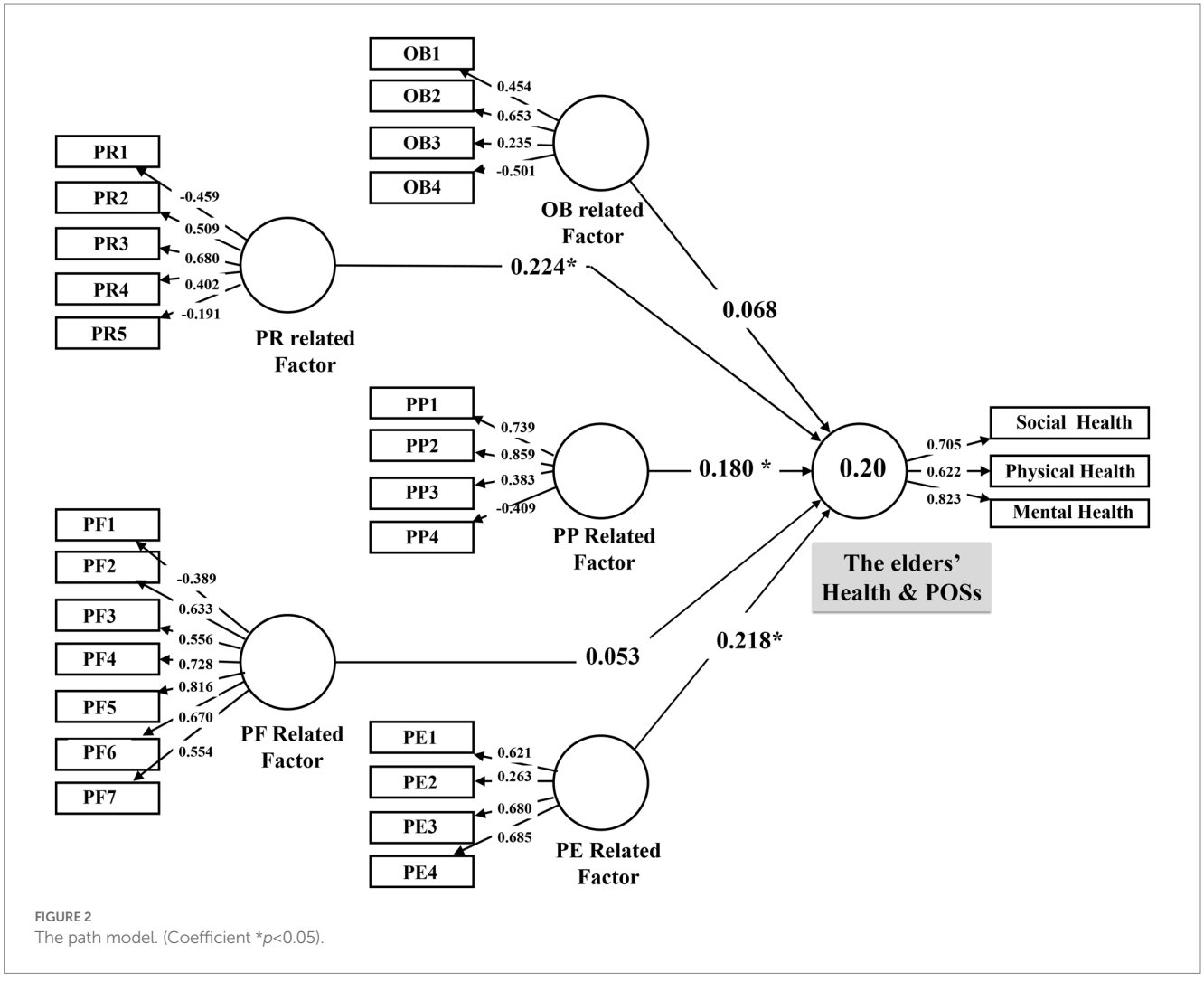

FIGURE 2
The path model. (Coefficient *p<0.05).

A more significant beta coefficient (β) among the supported latent variables would indicate a more robust effect from an exogenous latent construct on the endogenous latent construct. Table 4 and Figure 2 show that PF and PE factors had the highest path coefficient ($\beta = 0.224$ and $\beta = 0.218$) compared to other β values in the model. This indicates that these factors had a more significant variance and a more substantial effect on older people's health. The PP-related factors had the slightest impact on health ($\beta = 0.180$).

To Emphasize the model fit, our results indicate that the SRMR of our model was 0.095, showing that the model has moderate goodness to fit. The associated Chi-Square value was 1866.461, and NFI was 0.211.

Discussion

By adopting an ecological approach, we examined the relationship between the perceived and objective aspects of urban POSs and the health domains of older adults in poor urban neighborhoods of Tehran, Iran. Three health domains (social, mental, and physical) were evaluated based on an individual's perception of the place, which has its roots in the person-environment relationship, place features (both perceived and objective), and socio-demographic status. Thus, we have hypothesized and proposed a predictive path model. Based on the findings, the physical, mental, and social health in older adults is associated with some attributes of POSs as place preferences (Security, Fear of Falling Down. Way Finding and Perceived Aesthetics) and processes in the environment (Social Environment, Cultural Environment, Place Attachment and Life Satisfaction). Our study also emphasized the role of the personal aspect and socio-demographic status (such as Gender, Marital status, Education, and Occupation) in making older people healthy by using POSs in their neighborhoods, mainly the Frequency of being present in POS.

The predictive model revolves around the relationship between older adults' health and urban space features. It depends on place function (safety, landscape design, place aesthetics, cleanliness, amenities, and sense of comfort), older adults' place preferences (security of the environment, subject aesthetics, fear of falling down, and fear of getting lost), and place processes (social background, cultural features, sense of belonging to the place, and life satisfaction). In addition, the model examines the relationship between objective dimensions such as the density of land uses, residential density, the number of intersections in the unit of area, and the quality of the residential environment (new or deteriorated), as well as individual profiles such as gender, age, marital status, and frequency of visits to a POSs and health.

The results suggest that personal features, the process of place-time relationships, and place preferences are related to older adults' health. Older adults' health in urban spaces is a function of mental, social, and physical health. In contrast to most studies focusing mainly on physical health (49), the present study shows that social and mental health is more substantial among older adults in deprived areas. Accordingly, mental health's effect on general health is more vital than physical health (50). Also, for older adults, their physical and psychological health depends on their social health and social relationships.

In agreement with other studies (51), socio-demographic status substantially affects marital status. Education has the closest relationship with health among older adults since they cause individuals to pay more attention to their health and health-related behaviors. Having a spouse decreases the sense of loneliness and abandonment, enhancing one's health and quality of life. In this study, increasing presence in urban spaces influences older adults' health. The gender dimension shows that presence in urban spaces only affects the health of males. This is in line with the study on the health of older adults conducted in Japan (12).

Studying the relationship between health and the perceived features of urban space shows that the formation of place function that builds upon non-physical aspects of the environment has a closer relationship with older adults' health than place preferences and place function. In the non-physical dimension of place, older adults' most influential health factors are life satisfaction, sense of belonging to the neighborhood and urban space, attachment to the social environment, and cultural factors. The sense of belonging, formed by being rooted in a place and having a place-bound identity, creates stability and mental security in an individual. In addition, older people are usually unwilling to move to another place because they are bound to a place for their memories. Previous studies have mentioned the effect of place attachment on social health (52). Satisfaction with one's residential environment and belonging to the neighborhood and urban space creates a sense of comfort in older adults. Thus, urban space and local parks in dense neighborhoods act like one's own courtyard, enhancing a sense of control in older adults (53).

The role of the social environment as an opportunity for social interactions prevents the sense of abandonment and loneliness in older adults. Most studies regarded social relationships as a trigger of trust and support in older adults, increasing mental health and preventing anxiety and distress. Moreover, it will also enhance the social functioning of older adults, thus resulting in better relationships with family members and friends and boosting the sense of belonging in society. Thus, relatedness is the sense of belonging and being a member of the social environment, which was demonstrated to have strong relationships with positive feelings, life purposes, perceived vitality, personal development, and life satisfaction in older people (54).

Cultural factors such as the segregation of men and women and the limited presence of house pets due to Iran's cultural restrictions have less remarkable effects on older adults' health (7, 11, 53, 55).

After the process of the person-place relationship, place preferences have the most substantial effect on the relationship between health and urban space. Lack of fear of falling, sense of security, and empirical-affective aesthetics of urban spaces contribute to place preferences on older adults' health. Fear of falling down is a major preventive factor that depends on the individual's background (56), which has its roots in older adults' physical and mental health. The sense of security that results from the low level of crimes and uncivilized behavior can create a sense of comfort in the elderly and make them feel like they are in their courtyard in POSs.

Consistent with our findings, Fuller (57) states that the perceived difficulty of tasks, such as those used to control body posture, has a strong relationship with the prediction of risk, which is indicative of an emotional reflex to dangers, e.g., fear of falling (57). Therefore, anybody with a fear of falling down should limit outdoor physical activities, which, if not considered, eliminates the people with the fear of falling from the group at risk (1). Besides, if this feeling of fear through specially designed environmental spaces decreases, an increase will result in individuals' physical activity (56, 58), which may promote active aging (59).

Finally, the aesthetic experience of older adults, which results from perceiving harmony and geometry, could result in mental comfort and overall health. According to previous studies, protection against traffic, walking level and safe parks, the intensity of street noise (60), physical barriers, aesthetics, and crime (61) impact the health-related quality of life of older adults. Although previous studies have shown that the objective dimensions of place affect the health of older adults (34, 60, 62), the present study does not confirm such a relationship. In addition, this study does not show any relationship between older adults' perception of place function and their health.

One limitation of the present study is the restriction of the study scale only to deprived neighborhoods. Furthermore, our

study was conducted over 3 months; this can lead to different results if conducted at different time points of the year since it is most likely that older adults' perception of POSs differs between seasons.

This study's results can contribute to the design of public environments for older adults to improve their social, mental, and physical health. This makes possible the idea of aging in place through physical and non-physical interventions and providing a high-quality urban environment that meets the older peoples' sense of belonging and preferences. Our study highlights the importance of appropriate housing and providing POSs tailored to their needs for them to be able to socialize and participate in social-cultural events. Increasing social capital is another way to form social networks and social cohesion. Moreover, our study highlights the need to design spaces without barriers suitable for walking, provide protection against crime, and prepare the environment with fewer falls risk.

Conclusion

We found positive associations between Place preference, Process-in-environment, and personal health-related factors to elders' health (social, mental, and physical). Therefore, we recommend that older adults' preferences concerning outdoor spaces and their life satisfaction and relatedness (i.e., social interaction and place attachment) could be considered for planning and designing outdoor spaces' features before implementing urban management policies. The path model presented is a suitable approach to using various dimensions of the neighborhood environment, including objective and perceived features.

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 the Iran University of Medical Sciences. The patients/participants provided their written informed consent to participate in this study.

Author contributions

HB and AL created the study's concept and design. AL conducted the research, developed the methodology, and authored the article. SK used SPSS to analyze the analysis. PM offered thorough criticism of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Urban park system on public health: underlying driving mechanism and planning thinking

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The driving mechanism and planning thinking of the impact of urban park system on public health the mission of urban geography, urban and rural planning or landscape architecture are to coordinate the relationship between people and places, people and nature. The municipal park system is an important part of the urban green space system. In order to effectively play the role of the urban park system in promoting the health of urban residents. This manuscript studies the coupling relationship between the "urban park system" and the "public health system" by building a coordination model, reveals the driving mechanism of the urban park system affecting the benign development of public health, and clarifies the positive driving effect of urban parks on public health. Finally, based on the analysis results, the manuscript considers the optimal development strategy of urban parks from the macro and micro levels to promote the sustainable development of urban public health.

KEYWORDS

city park, public health, ecology, driving mechanism, analytic hierarchy process

1. Introduction

The process of urbanization is still advance. The sharp increase of urban population has resulted in the decline of environmental quality and the threat of ecological stability. The negative impact of urban space environment on public health is gradually exposed (1). On 25 October 2016, the Central Committee of the Communist Party of China and the State Council issued the Outline of the "Healthy China 2030" Plan, which deployed plans to enhance public health from the policy level. The fifth part of the outline highlighted the importance of "building a healthy environment," clarified its construction rules, and advocated strengthening the governance of environmental issues affecting health and promoting the healthy development of the people (2, 3). As a key component of urban green space system, urban park green space has a significant effect in purifying urban air and beautifying public environment.

At present, scholars at home and abroad have made many academic researches on the role of urban park system in promoting the healthy development of residents: Jiang Bin, Zhang Tian, William C. Sullivan and others discussed the impact mechanism of urban green landscape on public health (4), and explained the impact of urban green landscape on public health and well-being through five theoretical mechanisms. Yao Yanan and Li Shuhua reviewed the research on urban green space based on public health (5) and concluded that the mechanism of green space positively affecting public health may be to provide ecological products and services through natural elements in green space and promote healthy behaviors. Maming, Bob Mogol and others studied the factors that affect physical activity in green open space design (6), combed six factors

that affect physical activity based on space, place and perception, and established a preliminary indicator framework for physical activity factors in green open space. Green sport can bring positive short-term and long-term health results. Barton studied the best plan of nature and green sport to improve mental health (7), analyzed and evaluated the best plan of green sport needed to optimize self-esteem and emotion.

The research perspective on the impact of urban parks and green spaces on public health in European and American countries is unique and innovative: Zhao Xiaolong, Wang Mincong, and others studied the interaction between the planning and design of urban parks in Britain and the evolution of public health themes from the perspective of public health and well-being (8). In combination with social, political and economic background, health conditions and other factors, the public health appeal is described in six stages: preventing infectious diseases, solving urban environmental problems, paying attention to leisure sports, seeking social integration and promoting mental health, cultivating a healthy lifestyle, and building a common health of society and ecosystem.

Zhang Mengjia and others analyzed the classification system of urban parks in the United States (9). The urban park system of the United States has significant functions in promoting physical activity of its residents and improving the level of national public health. Therefore, one of the characteristics of its urban park classification is "physical activity demand oriented." The study takes Minneapolis city park system as an example to conduct in-depth research, and draws important experience and suggestions on China's "building a healthy China": re-examine the functional positioning of domestic city parks. City parks have become an important breakthrough in optimizing national fitness venues, and actively establish a classification system of city parks that is suitable for national conditions and oriented by physical activity needs, At the same time, pay attention to the "accessibility" indicators of urban parks.

A large number of studies above comprehensively revealed the mechanism of urban park system on public physical and mental health from multiple perspectives, but ignored the overall driving role of public "social health." Although some studies included "improving social capital" into the utility scope of urban parks, they did not consider social functions such as "improving esthetics and mitigating natural disasters," which is one-sided. This paper explores the social health effects produced by the urban park system in combination with relevant domestic and foreign studies, uses the principal component analysis method and the analytic hierarchy process (AHP) to build an evaluation index system of the ability of urban parks to promote public health development, constructs a coordinated development model to clarify the coupling relationship between the urban park system and public health, and reveals the driving mechanism of the urban park system to drive public health development, Clarify the detailed relationship between "promoting physical activity, creating ecological value, improving viewing experience, and enhancing social viscosity" and the driving effect of public health, to explain how the urban park system promotes the positive development of public health.

2. Methods

2.1. Influencing factors of human health

Human health is influenced by the combined effects of dominant and recessive factors, and the order and level of each factor's impact are different. According to the relevant research background (4), the distribution map of factors affecting human health is drawn, as shown in Figure 1.

Individual factors, factors of lifestyle habits, social factors, working and living environmental factors, and natural environmental factors seriously affect human health. While factors at various levels directly affect human health, there may be interactions: for example, the choice of human life and work style is due to social factors, the consideration of living and working factors; the way, field and space of public social interaction depends on the urban environmental conditions; the interaction of multiple factors gradually changes the human health status, and fundamentally reflects the level of social public health. The factor distribution map shows that the root cause of human health changes lies in external environmental factors. Urban parks are an important component of the external environment in which modern human beings live. Therefore, urban parks have an comprehensive irreplaceable effect on human public health, even exceeding the impact of human factors on health.

2.2. Principal component analysis

2.2.1. Determination of principal components

The principal component analysis method brings multidimensional factors into the same system for quantitative research, and describes the performance of the system with fewer evaluation indicators by simplifying complex impact indicators. The theory is relatively perfect and the statistical performance is relatively diversified. Based on the principal component analysis method, the

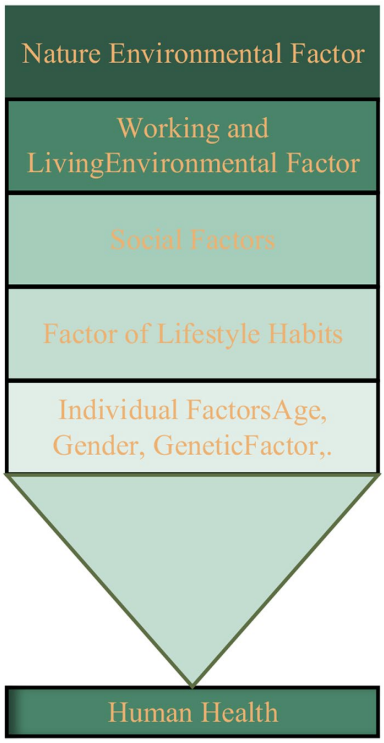

FIGURE 1
Distribution map of factors affecting human health.

main evaluation index of the evaluation index system, namely the content of the criteria layer, is determined to reduce the calculation amount of the evaluation of the ability of urban parks to promote public health development. Standardize the evaluation index data, and calculate the index. The correlation coefficient matrix is defined as R. The principal component calculation is applied to the three key variables of matrix R, namely, eigenvalue, variance contribution rate and cumulative contribution rate, which are marked as λi, Bi, Mm, the calculation method of variance contribution rate and cumulative contribution rate is shown in formulas (1, 2):

$$D_i = \frac{\varepsilon_i}{\sum_{i=1}^{p} \varepsilon_i} \quad (1)$$

$$H_m = \sum_{i=1}^{m} D_i \quad (2)$$

In the formula, the information amount of each principal component is described by D_i, and the information synthesis ability of the first m principal components is described by H_m. Take the first level indicators evaluating the ability of urban parks to promote public health development as the principal components, calculate their eigenvalue, variance contribution rate and cumulative contribution rate, and further determine the simplified principal components that can express the ability evaluation of urban parks.

2.2.2. Weighted comprehensive grade calculation

The weighted summation method is used to calculate the comprehensive score of the evaluation on the ability of urban parks to promote public health development. The calculation formula is shown in formula (3):

$$J = \omega_1 \times G_1 + \omega_2 \times G_2 + \cdots + \omega_i \times G_i \quad (3)$$

Among them, the indicator weight is ω_i represents, G_i represents the principal component, and its calculation formula is:

$$G_i = \sum_{x=1}^{l} q_{xi} \times A_{nx} \quad (4)$$

Among them, the factor load coefficient of the x index of the i principal component is expressed in q_{xi}, and the standardized form of the x evaluation index is expressed in A_{nx}.

2.3. Coordinated development model

Whether multiple systems are coordinated and properly coordinated can be reflected through "coupling degree" to judge whether they form a virtuous circle, clearly express the strength and interaction degree of the system or elements, and master the process of interaction between systems. The relationship between systems is complex and unbalanced, and the level of collaboration is good or bad. Therefore, the concept of "coordinated development degree" is used to evaluate the level of coordinated development between systems and the degree of both, so as to more accurately express the overall coordination level and synergy of the system. The coordinated development degree model consists of coupling degree model and coordinated progress degree model. Urban parks generate supply and public groups generate demand, so there is a definite coupling relationship between the two. In order to more accurately describe the driving impact of the urban park system on public health, this study uses the coupling degree to express the driving relationship between the two. When the coupling degree is advantageous, it is considered that the driving effect is good.

3. Empirical research

3.1. Overview of the study area

The Caishiji Riverside Cultural Park in Ma'anshan, Anhui Province, China is chosen as the research object. The research area is situated in the north of the Yushan District Quarry Scenic Area in Ma'anshan City. It is the only living shoreline of the city near the river in terms of ecological protection, extending the original quarry scenic spot in area, and creating a riverside ecological and cultural place for the public to live by virtue of its profound historical and cultural heritage. Caishiji Riverside Cultural Park is adjacent to the Yangtze River in the west, Liufen River in the north, Xishan Mountain, Xiaojiuhua Mountain and Hebao Mountain in the east, and Suoxi River in the south. It covers an area of 3.54 square kilometers, as shown in Figure 2. The park has been planned and laid out with "three parks and two axes" as the core. "three parks" refers to the three regional settings in the north, south and middle of the park: (1) it shows the development process of Ma'anshan's industrial civilization and keeps pace with the era of ecological and environmental protection. (2) The south area of the park is close to Caishiji, where there are a series of cultural parks, such as the Buddhist Culture Park of Xiaojiuhua Mountain, the War Relics Park of Hebao Mountain, and contains a long and touching historical and cultural connotation. (3) The central area of the park is designed as a leisure park, because the terrain of this part is relatively flat, with a safe natural environment, and a supporting leisure complex has been built. The "two axis" refers to the "north–south landscape ecological axis" formed by the original wetland and the "east–west development axis" formed by the connection with the urban center. The intersection of the two axes is built into a square park.

For evaluating the ability of urban parks to promote public health development in Caishiji Riverside Cultural Park, so as to build a driving mechanism for the impact of an urban park system on public health, and obtain relevant thinking on urban park planning. This park is under a large flow of people, rich water landscape and green space, and complete cultural facilities. It is a great place for local residents to provide daily entertainment, fitness, and social interaction. A questionnaire survey was undertaken among 50 residents within the park. Each resident distributed two questionnaires. One questionnaire investigated the residents' evaluation of the park's value creation, and the other questionnaire investigated the relevant issues of public health, including "physical health, mental health, and societal health." The above questionnaires were used as data samples for the evaluation

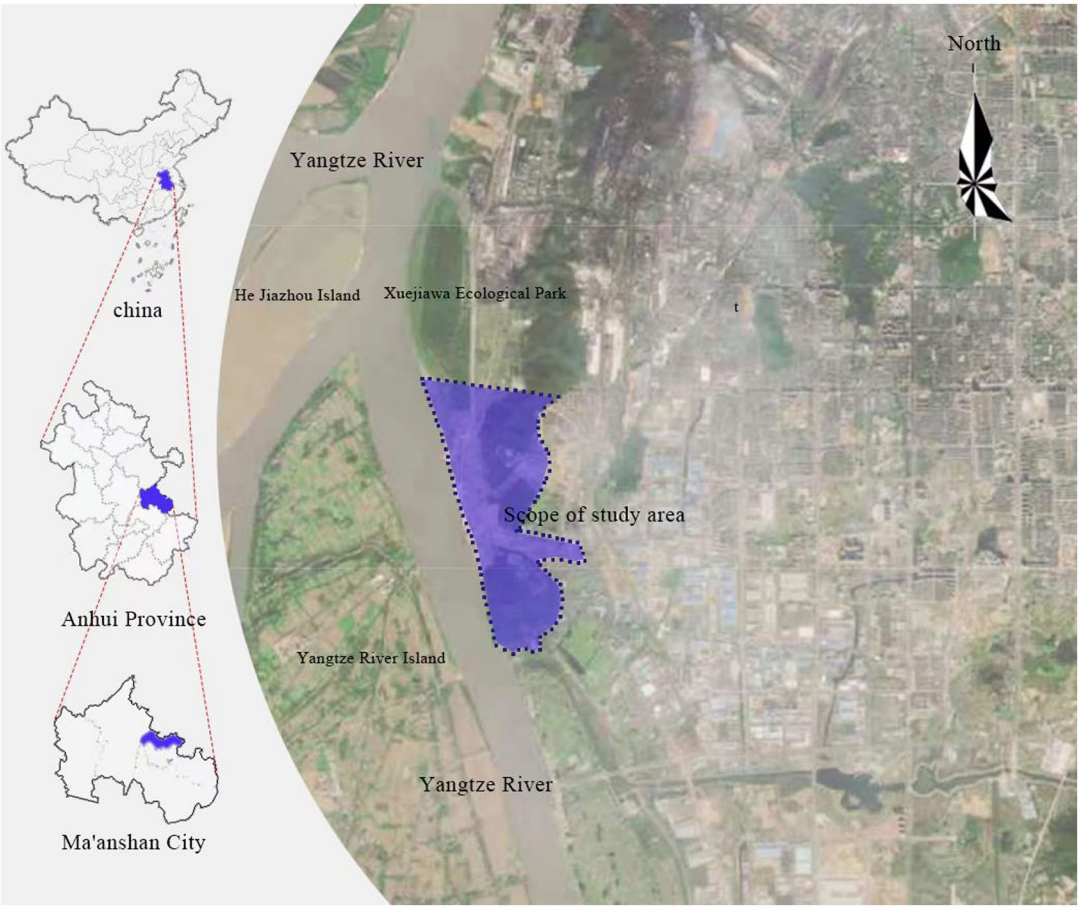

FIGURE 2
Overview of the Study Area.

TABLE 1 Detailed information statistics of questionnaire respondents.

Research elements	Type and number of people					
Gender	Male (24 persons)			Female (26 persons)		
Age	Under 14 years old (2 persons)	15–18 years old (4 persons)	19–25 years old (5 persons)	26–40 years old (15 persons)	41–65 years old (12 persons)	Over 65 years old (12 persons)
Education	Junior high school education and below (4 persons)	High school education (12 persons)	Higher vocational college degree (22 persons)	Bachelor degree (8 persons)	Master degree (3 persons)	Doctoral degree (1 person)
Park activity stay time (hours)	0.5 h and below (10 persons)	0.5–1 h (12 persons)	1–2 h (10 persons)	2–4 h (14 persons)	4–6 h (2 persons)	More than 6 h (2 persons)
Purpose of park activities	Fitness and exercise (25 persons)	Accompany the older adult and children (24 persons)	Social networking with friends (12 people)	Collective activities (7 persons)	Walking and leisure (24 persons)	Cultural exchange (8 persons)
Park activity period	Before 7:30 a.m. (10 persons)	7:30 a.m.–11:30 a.m. (14 persons)	11:30 a.m.–2:00 p.m. (2 persons)	2:00 p.m.–5:00 p.m. (16 persons)	5:00 p.m.–7:00 p.m. (6 persons)	After 7 p.m. (2 persons)

of the park's ability to drive public health. In addition, in-depth interviews were conducted with residents on pertinent issues. Fifty respondents, composed of men and women of all ages, have certain research value and reliability. The detailed information of the respondents is given in Table 1.

3.2. Determination of principal components of evaluation indicators

The expert team preliminary determined that there are 8 primary indicators for the evaluation of the ability of urban parks to promote

public health development, which are respectively: promoting physical activity (G1), promoting cultural communication (G2), creating ecological value (G3), improving viewing experience (G4), creating entertainment atmosphere (G5), enhancing social viscosity (G6), creating leisure experience (G7), and enhancing esthetic meaning (G8). Based on formulas (1, 2), the contribution rates of the eight principal components are calculated, sorted from high to low, and their cumulative contribution rates are calculated, as shown in Figure 3.

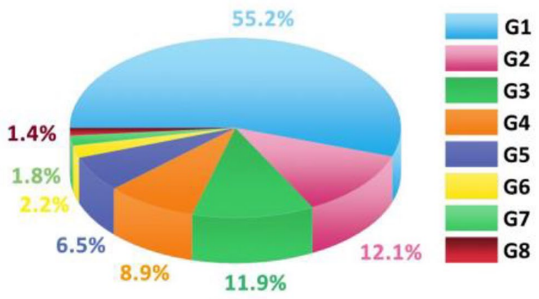

FIGURE 3
Statistics of contribution rate.

The factors with a cumulative contribution rate of more than 85% are taken as the principal components. According to the analysis of the data in Table 2, the cumulative contribution rate of the first four factors G1~G4 is 88.1%, which meets the standard that the cumulative contribution rate is more than 85%. Therefore, the first four factors "promote physical activity, create ecological value, improve viewing experience, and enhance social cohesion" are taken as the principal components of the evaluation of the ability of urban parks to promote public health development, which is the final criterion layer. It achieves the purpose of expressing the evaluation of park capacity and reduces the amount of calculation.

3.3. Construction of evaluation index system and calculation of index weight for urban parks' ability to promote public health development

According to the results of the principal component analysis, it is determined that the main factors for urban parks to promote the development of public health include promoting physical activity, creating ecological value, improving viewing experience, and enhancing social cohesion. As primary indicators, each primary indicator includes a total of 15 secondary indicators. The construction of the urban park supply evaluation indicator system is shown in Figure 4.

TABLE 2 Comparison of relative importance of criteria level indicators.

Criterion level indicators	Promote physical activity (B1)	Create ecological value (B2)	Improve viewing experience (B3)	Enhance social viscosity (B4)
Promote physical activity (B1)	1	2	3	5
Create ecological value (B2)	1/2	1	2	3
Improve viewing experience (B3)	1/3	1/2	1	2
Enhance social viscosity (B4)	1/5	1/3	1/2	1

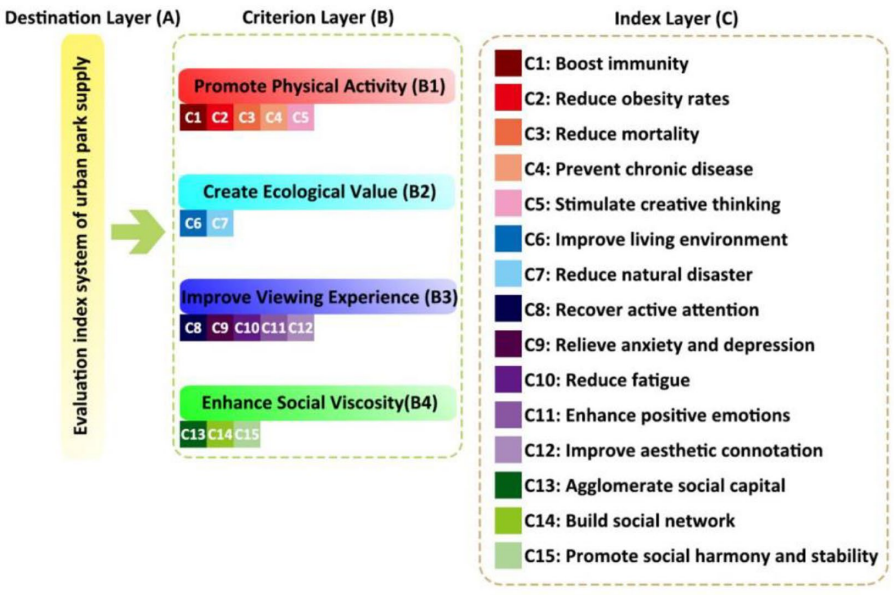

FIGURE 4
Evaluation index system of urban park supply. **(A)** destination layer; **(B)** criterion layer; **(C)** index layer.

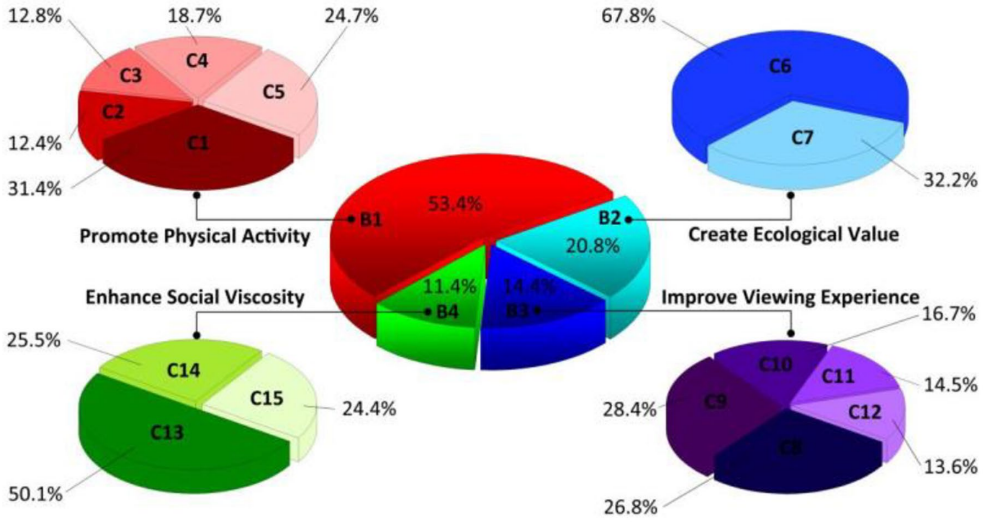

FIGURE 5
Weight of urban park supply evaluation index.

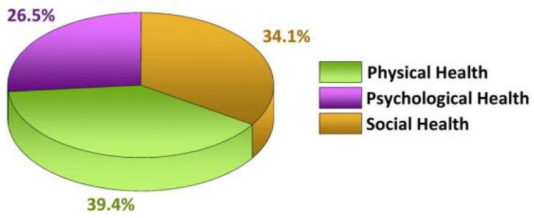

FIGURE 6
Weight of public health evaluation indicators.

In this study, 20 experts were given two factor comparison questionnaires, and different matrix construction results and different weight calculation results were obtained based on 1–9 scale method; Then calculate the arithmetic mean value of the weight results obtained by 20 experts in the field as the final index weight results. Table 2 shows the judgment matrix of the criteria level of the evaluation index system for the ability of urban parks to promote public health development.

The figures in Table 2 indicate the relative importance of the two evaluation indicators for the target layer. For example, under the goal of promoting public health in urban parks, the importance of "improving viewing experience" is 1/2 compared with "creating ecological value."

It is calculated that the weight of indicators at the criterion level is to promote physical activity—3.107, create ecological value −1.442, improve viewing experience −0.693, and enhance social viscosity −0.322, with normalized weights of 0.534, 0.208, 0.144, and 0.114, respectively. Finally, the indicator weight passed the consistency test, and the calculated weight results can be used as valid data (10).

According to the above calculation method and consulting experts' opinions, the survey results were integrated with reference to relevant literature, a judgment matrix was constructed, and finally the weights of urban park supply evaluation indicators and public health evaluation indicators were calculated as shown in Figures 5, 6.

Using the formula (3) weighted summation method, it is calculated that the park driven public health capacity in the study area is classified into three levels, and the evaluation level is divided into five levels. The level of the park driven public health capacity in the study area is medium. The "target layer" realizes the improvement of public health in the "indicator layer" through the "criteria layer." Therefore, in this logical relationship, the four factors of "promoting physical activity, creating ecological value, improving viewing experience, and enhancing social cohesion" are coupled with the "physical health, psychological health, and social health" of public health. The former plays a driving role in the latter, and becomes the factor of "driving" the development of public health in urban parks.

3.4. Construction of coordinated development degree model

This study uses coupling degree to express the driving relationship between the two to objectively interpret the driving impact of urban park system on public health. When the coupling degree is good, it is considered that the driving effect is good. Based on the accuracy and feasibility of data acquisition, from the perspective of the value created by urban parks and the benefits obtained by public residents, two subsystems of "urban park supply" and "public health demand" are constructed. The "urban park supply" subsystem contains four positive indicators, and the "public health demand" subsystem contains three positive indicators. Based on the analysis results in Table 3, "promote physical activity, create ecological value, improve viewing experience, and enhance social viscosity" is defined as the supply indicator of urban parks, and "physical health, mental health, and social health" is defined as the demand indicator of public health.

Calculate the fuzzy membership function of the obtained urban park index weight, and obtain the membership value of the urban park supply index; The comprehensive evaluation index of urban park supply Xi and the comprehensive evaluation index of public health

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TABLE 3 Grading of coordinated development stage (driving stage) of subsystems.

Coordinated development	0~0.39	0.40~0.49	0.50~0.59	0.60~0.69	0.70~0.79	0.80~0.89	0.90~1.0
Coordination level division	Maladjustment stage	Approaching maladjustment	Basic coordination	Primary coordination	Intermediate coordination	Good coordination	Very coordinated

demand Yi are obtained based on the weighted average method. The specific methods are shown in Formulas (5, 6):

$$X_i = \sum_{i=1}^{4} x_j \times a_j \tag{5}$$

$$Y_i = \sum_{i=1}^{3} y_j \times b_j \tag{6}$$

Where, x_j represents the membership value of park supply indicator j, and y_j represents the membership value of public demand indicator j; Entropy weighting coefficient is described by a and b. Based on this, the coordinated development model of urban parks and public health is constructed as follows:

$$P = \sqrt{C \times T} \tag{7}$$

$$\lambda = \left[\frac{X_i \times Y_i}{\left(\frac{X_i + Y_i}{2} \right)^2} \right]^r \tag{8}$$

$$G = \alpha \times X_i + \beta \times Y_i \tag{9}$$

In the formula, the coordinated development and coupling degree of urban park supply and demand are, respectively, P, λ. The comprehensive evaluation index is expressed as G; The adjustment coefficient and undetermined coefficient use r and α, β. It means that the former value is 2 and the latter value is 0.5, respectively.

The relationship between urban park supply subsystem and public health subsystem is defined by reference to the ArcGIS natural breakpoint classification method using numbers: (1) Antagonism stage: 0 < coupling degree ≤ 0.4; (2) Running in stage: 0.4 < coupling degree ≤ 0.8; (3) Coordination stage: 0.8 < coupling degree ≤ 1. The coordinated development stage (driving stage) of the two subsystems is further classified, and the results are shown in Table 3.

4. Driving mechanism and planning thinking

4.1. Driving mechanism

Urban parks are external environmental factors that affect human health and significantly affect public health (11). It can be seen from the comprehensive evaluation results of public health level driven by parks in the study area that among the four public health drivers, public groups can have a positive reaction of "promoting physical activity" when visiting urban parks. The weight value of 0.534 proves that "promoting physical activity" is a significant function of urban parks to drive the development of public health, and it brings health benefits for the public at the physiological and psychological levels; The weight value of providing ecological services is 0.208, which is second only to "promoting physical activity" in driving the development of public health; The weight of providing ornamental services is 0.144, which has played a positive role in driving the development of public health; Although the weight of social capital is only 0.114, it plays a positive role in improving capital accumulation, increasing positive emotions and social harmony and stability.

Based on the coordination degree model, the coupling relationship between the urban park supply subsystem and the public health demand subsystem is calculated. The level of their coordinated development is "good coordination," and the coordinated development degree is 0.81. Moreover, the comprehensive evaluation index of the urban park supply is greater than the comprehensive evaluation index of the public health demand, presenting a health impact situation of supply exceeding demand. It can be seen that the urban park system has a positive impact on public health, forming a positive driving mechanism. According to the research results, the mechanism of urban park system driving public health is shown in Figure 7.

It can be seen from the analysis of Figure 7 that the driving function of urban parks for public health is mainly manifested in three levels: "physical, psychological and social." The process of driving public health by urban parks includes four intermediary factors: "promoting physical activity," "creating ecological value," "improving viewing experience," and "enhancing social viscosity," which further generate a positive public health driving effect and ultimately achieve the goal of public physical health, psychological health, and social health.

4.2. Driving mechanism analysis

4.2.1. Driving mechanism of urban parks for public "physical health"

1. Enhance immunity and reduce obesity rate. Urban life has led to great pressure on public life and work, and the frequency of physical exercise and physical activity has decreased. Urban parks have become an important link for the public to increase the number of physical activities (12). A large number of practical studies have proved that the closer the living area is to the city park, the stronger the willingness of physical activity is. Residents can generate physical activity through the city park to enhance the immunity of the urban population and reduce the obesity rate.

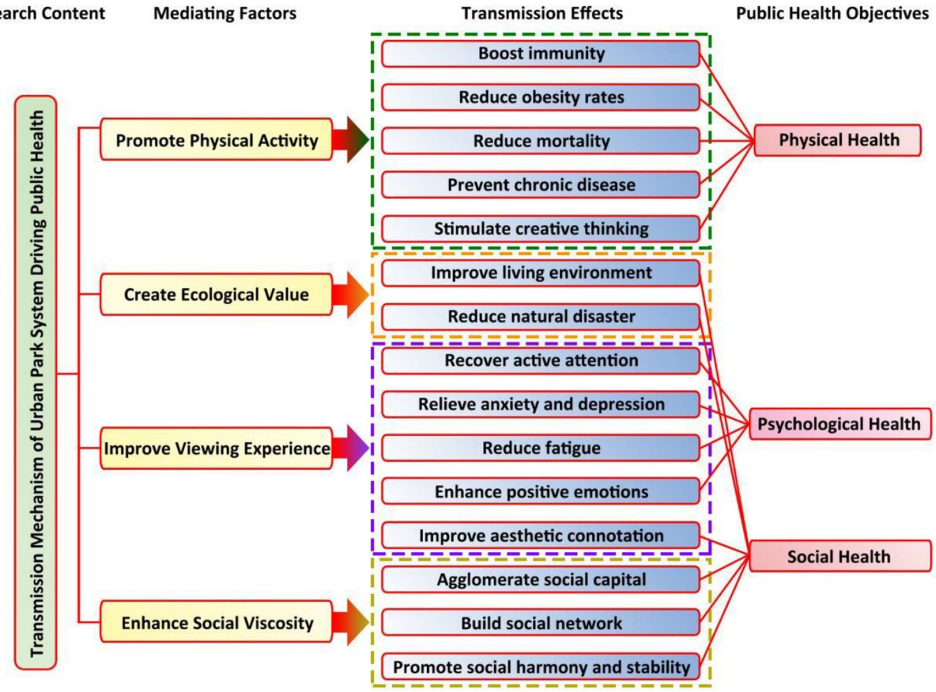

FIGURE 7
Driving mechanism.

2. Reduce mortality. Walking in urban parks with dense trees and vegetation is beneficial to increase the scale of adult pain resistant active protein, avoid accelerated secretion of adrenaline, curb the incidence rate of related diseases, prolong the life span of the older adult population, and reduce mortality; Pregnant women living near urban parks have a high frequency of activities around green vegetation, and the probability of premature delivery and underweight infants is relatively low.
3. Prevent chronic diseases. Inhaling polluted air can easily lead to respiratory diseases and other chronic diseases. Garden plants can release oxygen, absorb pollutants, inhibit bacteria, and improve the quality of living air (13–15).
4. Stimulate creative thinking. Physical activity and exercise can easily lead to positive emotions. Proper physical activity in the park system can help increase individual's sense of energy and reduce tension. When people are dominated by positive emotions, they do not need to use more psychological resources to solve problems, but focus on creative thinking, which is more likely to show highly creative behavior, thus creating a good atmosphere for creative thinking. Therefore, the urban park system creates a place for individual activities and indirectly stimulates individual creative thinking.

The following is the interview content of park residents sorted out in this study (the first female resident and the first male resident are expressed by F1 and M1 respectively, and so on):

> Author: Do you often go to Riverside Culture Park for physical activities, and do you have any changes in your physical feelings, health status, and thinking state? You can talk about your life experience in terms of weight change, immunity, creative thinking, etc.
>
> Resident (F1): I basically come here every morning and afternoon for activities. The air here is very good, and the air humidity in the adjacent waters is very good and comfortable; I feel comfortable when I come to the park for activities. I feel much less physical burden. Recently, the chance of catching a cold has obviously decreased due to the severe flu.
>
> Resident (F2):Every time I am upset by my work, I will come here to relax and do some exercises. My mood will be relaxed and I will have more desire and confidence to solve the problems of work.

It is obvious from the residents' answers that their physical condition and thinking state have been significantly improved through physical activities in Riverside Culture Park, which has promoted the residents' physiological health.

4.2.2. Public "psychological health"

1. Active attention recovery. The green natural environment is a typical "restorative environment." Human exposure to the green natural environment can produce "stress recovery response," reduce tension and restore attention.
2. Relieve anxiety and depression, and release psychological pressure. The ornamental function of urban parks is more prominent, creating a space environment for relaxation, meditation and appreciation of plant water bodies (16).

3. Reduce fatigue. Modern urban park design is generally based on a large amount of research on the public's esthetic taste and practical needs. The planning and design of the park system is remarkably systematic, realizing the organic combination of individual "psychology - spirit - external environment." Therefore, urban parks are not only leisure places to reduce physical fatigue, but also outdoor spaces to remove psychological fatigue. It was mentioned in the interview that:

> Visitor: What time do you choose to come to the park for leisure activities? What changes do leisure time make you?
>
> Resident (M1): On weekends and holidays, they usually come with their families. They usually have less rest time and have a lot of work pressure. Playing in the park allows me to relax my tense nerves. My depression and anxiety at work are reduced. Seeing the green landscape and cultural influence, the whole person is relaxed.
>
> Resident (M2): I usually have a lot of study pressure. I live near here. I often come here with my friends during holidays to see the green trees to relieve my visual fatigue; When I came home from the park, I felt very comfortable, and my idea of doing homework became broader.

According to the interview with residents, the physical activities of residents in Binjiang Park can reduce their psychological fatigue, relieve their anxiety, and release their psychological pressure, thus realizing their psychological health.

4. Increase positive emotions. In the field of epidemiology in the United Kingdom, the impact of environmental beauty on public health has been studied in depth. With a large number of beautiful landscape images as data samples and multiple regression analysis as a tool, it has been confirmed that both landscape beauty and greening are conducive to public health. The pleasant scenery of urban parks gives people visual enjoyment, gradually eliminating the public's sense of loss and negative emotions, and increasing positive emotions (17, 18).

4.2.3. Public "social health"

1. Improve the living environment. In the 1960s, American epidemiology had found the law of high mortality rate of urban high temperature heat wave. For example, 85% of the more than 200 deaths in St. Louis in July 1966 occurred in cities. It can be seen that the urban heat island effect leads to local climate change, which increases the mortality of urban population. Under the effect of urban heat island, the intensity of high temperature in urban areas is intensified. The temperature in urban areas is slow at night. Urban residents are under the heat stress of alternating black and white for a long time. The mortality of people with poor physical conditions is greatly increased. In addition, respiratory diseases caused by urban air pollution have become a great threat to human survival. The ecological value created by the urban park system plays a positive role in air purification and greenhouse effect mitigation, and cannot be replaced in improving the living environment (19).
2. Mitigate natural disasters. In recent years, extreme weather, climate anomalies and other factors often lead to flood disasters. In addition, the construction of urban drainage systems is very different, and the construction of sponge cities is insufficient. The surface water infiltration of many urban streets is difficult, which increases the probability of flood disasters. The urban park system includes large-scale forest vegetation, which has played a positive role in blocking floods and pollutants.
3. Improve the esthetic connotation. In recent years, the planning and construction of China's urban park system has favored "cultural inheritance and development," and the layout and artistic expression of urban parks have been carried out by drawing on the techniques of creating beauty from Chinese classical gardens, which not only shows the unique esthetic connotation, but also is of great benefit to the pleasure of individual material life and spiritual life. Urban residents unconsciously accepted the influence of garden art when they were enjoying the park. The beauty of artistic conception and form displayed in the park design has imperceptibly improved the individual esthetic connotation and taste.
4. Gather social capital. Social capital generally refers to the characteristics and resources of social organizations brought about by the association between individuals or groups to optimize social efficiency. Although the weight of social capital is only 0.114, it plays a positive role in improving capital accumulation, increasing positive emotions and social harmony and stability. A large number of studies have confirmed that strong social ties benefit from the support and maintenance of urban park green space, outdoor gathering activities and other factors. Urban parks create frequent social opportunities, strengthen social ties between public groups, and maintain existing social capital; The groups that go to the common city park become familiar gradually, driving the public to carry out social contact activities regularly and repeatedly, forming an expanding social bond beyond the scope of daily social contact, and taking common interests as the carrier to improve the degree of capital accumulation.
5. Build social networks. In the information age, the Internet has become the main virtual tool for modern people to socialize. The urban park system has become a diversified real space for residents to relax and socialize. It has derived the static social models of tree lined paths, natural landscapes, sunshine lawns, water games, sports and other dynamic social models, as well as the organizational social models of fitness organizations, dating organizations, environmental protection organizations, which constitute the link between urban residents, It is helpful for urban residents to build and expand their own social networks. The construction of the urban park system has avoided the closed communication defects brought by the virtual social way, enhanced the social viscosity, and promoted the healthy development of public social communication. It was mentioned in the interview that:

> Interviewer: Do you usually come here for activities or do some leisure projects with others?
>
> Resident (F3): I came here to chat with friends. The ecological environment here is good, with trees, water and cultural landscape. I can find many topics when chatting with friends.
>
> Resident (M3): Some retired friends and I often get together here. There is enough time in the daytime to talk about poetry and historical stories. The historical and cultural atmosphere here is particularly good.

It can be seen from the interview that Riverside Culture Park creates a good outdoor space for group activities, provides a private and eco-friendly place for friends to socialize and cultural exchanges, and helps residents achieve the goal of social health.

6. The society is harmonious and stable. The foreign research on the relationship between tree canopy and crime rate shows that increasing 10% canopy coverage can reduce the crime rate by about 12%; There was a study in Chicago that found that most of the living places of groups with low crime rate and stress behavior frequency were green vegetation spaces, and the safety level of such areas was high; Therefore, good park vegetation coverage can strengthen social equality, effectively enhance social cohesion, reduce criminal acts, and contribute to social harmony, security and stability.

4.3. Planning for urban park system construction

The driving mechanism of the impact of the urban park system on public health built in this study not only considers the psychological and physical health aspects, but also integrates into the social health goals. The analysis of the public health impact mechanism is relatively comprehensive, but the evaluation system of the impact of the urban park system on public health is not perfect and lacks detailed rules for evaluation; At present, the urgent situation of the COVID-19 epidemic urgently needs to build an outdoor epidemic prevention and control space to enhance the ability of social epidemic prevention; The application of artificial intelligence technology in park data collection and environment perception is increasingly mature, which can quickly and timely capture the dynamics of the park environment and reduce the cost of manual management (20–24). Based on the above considerations, a framework layout has been made for the construction of the urban park system, as shown in Figure 8.

4.3.1. Construction of urban park system health impact assessment system

Only by correctly recognizing the existing problems and advantages of urban parks can we formulate reasonable planning strategies in a timely manner. Therefore, it is urgent to build a health impact assessment system for the urban park system to clarify the direction of improvement of the urban park system. The health impact assessment technology in the field of green space planning in developed countries in Europe and the United States has developed relatively well, forming a systematic theoretical system. As the theoretical and practical support for the healthy development of cities, the health impact assessment technology has been applied to the green space planning projects of urban parks. The study preliminary constructs the health impact assessment system of urban parks, as shown in Table 4.

Table 4 outlines the objectives and contents of the three stages of "macro planning," "intervention planning," and "micro planning," providing reference for accelerating the construction of the health impact assessment system of urban parks. The health impact assessment technology of urban parks adheres to the principle of "health promotion" (25, 26). Considering the impact way and extent of the green space planning results of urban parks on public health, the planning decision-makers can adjust the landscape design scheme according to the health impact assessment report to optimize the public health function of urban parks. In addition, the health impact assessment has identified ways for urban park planning to improve health, and has used limited capital investment to play a greater ecological and social benefits. China urgently needs to speed up the construction of the urban park green space health impact assessment system, enhance the public health awareness of decision-makers, achieve regional economic and cultural prosperity by optimizing

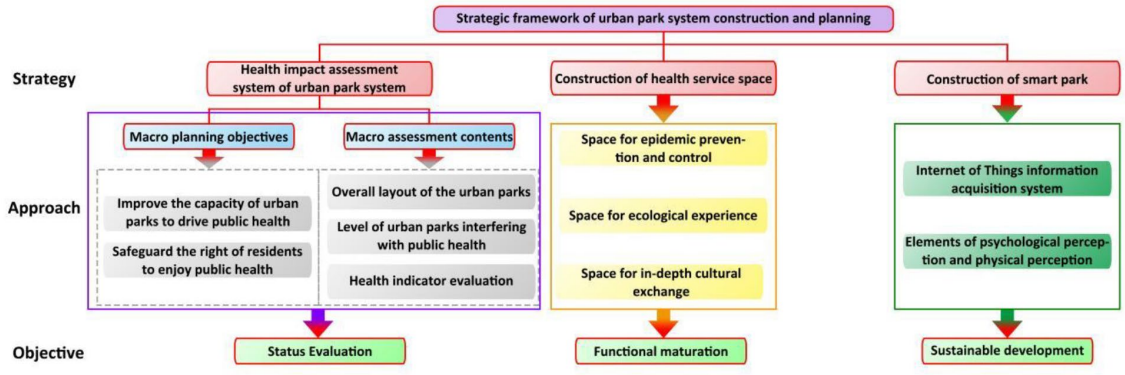

FIGURE 8
Thinking framework of urban park system construction planning.

TABLE 4 Health impact assessment system of urban park.

Planning level	Macro planning	Intervention program	Micro-planning
Assessment target	Optimize the ability of urban parks to optimize public health, and ensure that urban residents enjoy equal rights to public health.	Optimizing the degree of closeness of development control to public health.	Pay attention to the microscopic scenery of urban parks and strengthen the control of monitoring functions.
Evaluation content	The overall structural layout of urban parks, health indicators, and the level of indicators that interfere with public health.	The structural layout of plants, water bodies and hard buildings, the indicators of the elements of the garden, and the level of indicators that interfere with public health.	The layout and structure of micro-elements, the level of micro-elements interfering with public health.

public health, and promote the sustainable and healthy development of the urban park system.

4.3.2. Add health service space

The construction of health service space focuses on epidemic prevention and control space, and the severe epidemic situation highlights the key of emergency sites. With convenient transportation, open space and good ecological environment, urban parks are the best choice for epidemic prevention and evacuation, disaster prevention and mitigation. The central area of Caishiji Riverside Culture Park is a leisure park, with flat terrain and good greening, which is suitable for use as a flexible space for epidemic prevention and emergency services to meet the diversified needs of emergency events (27, 28).

4.3.3. Smart park layout

The smart park layout applies diversified intelligent management technologies to coordinate the integrated development of environmental, social and economic benefits. Spatial pattern design, plant population planning, and public facilities building, these basic park planning and management data can be recorded in the form of the Internet of Things, which combines the Internet of People and the Internet of Environment. The information feedback and update system of Smart Park provides data support for future park construction and update, and promotes the sustainable development of urban parks (29, 30, 31).

5. Conclusion

The subject of driving public health development by urban park system involves multiple cross disciplines, which complement and penetrate each other. This research comprehensively excavated the link elements among landscape science, psychology, public health management and other disciplines, and conducted in-depth research on the mechanism of urban park system driving public health from the two levels of "driving mechanism construction" and "public health planning thinking":

In the future research on the relationship between urban parks and public health development, on the one hand, we should strengthen the quantitative research on the driving effect, analyze the causal relationship between urban parks and public health based on the correlation research, and fully consider the extent to which the urban park system promotes the healthy development of the public; On the other hand, take the application of artificial intelligence technology as the decision-making leader of urban park planning and design, use intelligent algorithms to conduct research in the preliminary feasibility study, better carry out the planning scheme layout and node refinement of urban park system, and further revise the interpretation framework of the urban park system driving public health mechanism proposed in this paper.

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.

Author contributions

CZ contributed the central idea, analyzed most of the data, wrote the initial draft of the paper, contributed to refining the ideas and carrying out additional analyses and writing—review and editing. YZ and QS contributed to writing—review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Awakening the sleeping giant of urban green in times of crisis—coverage, co-creation and practical guidelines for optimizing biodiversity-friendly and health-promoting residential greenery

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As multiple crises deepen existing inequalities in urban societies within and between neighborhoods, strategically integrating nature-based solutions into the living environment can help reduce negative impacts and improve public health, social cohesion, and well-being. Compared to public green such as parks, semi-public residential greenery is rarely studied, is regularly overlooked by planners, and often receives step-motherly treatment from architects and housing companies. We approximated the area of residential greenery of modernist multi-story apartment complexes in Berlin, Germany. We surveyed residents' suggestions for improving their living environments in vulnerable neighborhoods, report on co-creation experiences, and provide a practical guideline for optimizing health-promoting residential green spaces. The semi-public open space on the doorstep of two-thirds of Berlin's population is highly fragmented and, in total, has a similar area as the public green spaces and a great potential for qualitative development. Just as the suitability of different nature-based solutions to be integrated into the residential greenery depends on building types, resident demands differ between neighborhoods. Residents called for more involvement in design, implementation, and maintenance, frequently proposing that biodiversity-friendly measures be included. As there is no universal solution even for neighborhoods sharing similar structural and socioeconomic parameters, we propose, and have tested, an optimization loop for health-promoting residential greening that involves exploring residents' needs and co-creating local solutions for urban regeneration processes that can be initiated by different actors using bottom-up and/or top-down approaches in order to unlock this potential for healthy, livable and biodiversity friendly cities.

KEYWORDS

co-creation, environmental justice, ecosystem services, green gentrification, green regeneration, nature-based solutions, residential greenery, social cohesion

1. Introduction

Existing inequalities in our societies are exacerbated in times of crisis (1, 2). People's perception of crises depends on whether, and to what extent they have resources available to deal with their impacts (3). There is growing evidence that urban green and blue infrastructure can mitigate crisis impacts and strengthen citizens' resilience by contributing to public health, social cohesion and overall well-being (4–10) and influencing also real estate market (11). Unfortunately, however, socio-economically vulnerable neighborhoods are often exposed to more environmental stressors such as noise, air or water pollution, and heat stress, but have less access to high-quality urban green and blue structures, even though they need them most. This is conceptualized as environmental (in)justice (12, 13). The need for green regeneration of our cities, and in particular in those neighborhoods that suffer environmental injustice, is already being considered by urban planners, developers and administrators (14–16). Although general strategies for greening cities and promoting urban biodiversity are becoming more common (17), standard implementations beyond demonstration projects remain rare and do not cover the city as a whole (4, 18, 19). For example, the focus of urban planners tends to be on urban parks and public green (7), often underutilizing the greening potential of other spaces. Mainstreaming and practical guidelines facilitating incorporation of nature-based solutions into daily urban design practice of those areas are still largely absent (18, 20).

The residential environment is an urban space where people spend time every day and can host many nature-based solutions such as gardens, green roofs and facades, ponds or pergolas. Such residential greenery, defined as the green (and partially blue) of the immediate surroundings of the residential buildings regularly created in connection with the construction of the respective settlements (21), is rarely studied, is often overlooked by planners and is accorded step-motherly treated by architects and housing companies (21). These green structures undergo continuous changes over time according to the individual developmental pathways of the housing estate including socio-economic ups and downs (22–26). At the same time, due to the compact city approach, it is under strong pressure from urban (re) densification trends (27, 28).

The perspectives on green around housing developments are very diverse. Many studies in the last decade have shown that property value gains from green in their surroundings (29), and can lead to green gentrification (30, 31) and urban green grabbing (when new residential projects are placed adjacent to existing or new green spaces; (32)). For communal housing companies and "non-profit housing associations", the residential green on their property and its design and maintenance are seen primarily as a cost factor, to be optimized in terms of duration, cost and layout (33). As gardening and maintenance costs are added to the operating costs of the apartments, they are passed on directly to the tenants who, though the greatest beneficiaries of high-quality space, also have an interest in reducing costs. At the same time, due to their public accessibility, such green spaces provide multiple ecosystem services to the neighbors and beyond (34), and, during the pandemic, were of daily benefit to local residents (9). While passive uses (e.g., enjoying the sun and fresh air) outweighed active uses (e.g., meeting neighbors, doing sports; (35)), during lockdowns, residents used these green spaces even more often and more actively as a health promoting resource and also as a space to overcome isolation and to meet neighbors. Thus, the role of residential greenery as a social tissue within the urban fabric increased (9).

Again, although green space is commonly associated with biodiversity (36), we know little about residents' preferences regarding biodiversity-friendly compared to "just greening" measures. Besides, as neighbors' preferences on residential green can be quite antagonistic regarding different use or design options (e.g., wild growing vegetation vs. English lawn; (9, 35)), enhancing the welcoming qualities and the motivation to be physically active by implementation of adequate elements is crucial.

Drawing on experiences of testing different governance approaches for co-creation of nature-based solutions under conflicting stakeholder interests to ensure inclusiveness in urban regeneration projects (20, 37, 38), optimization of health-related services of residential green can involve diverse actors and governance constellations for enhanced multifunctionality and to maximize the adaptability to diverse and changing residents' needs across different cultures and generations (9) in times of crisis and beyond.

Here, firstly, we aim to access the area covered by the semi-public residential greenery of the modernist housing complexes in Berlin, Germany. Secondly, we take a step forward by linking scientific results regarding the status quo and functionality of residential greenery with decision making on the implementation of health promoting nature-based solutions nearby multi-storey housing complexes. We do this by analyzing residents' suggestions regarding green regeneration, biodiversity-friendliness, quantitative and qualitative development of the residential greenery, by sharing insights from co-creation workshops with local residents, and by proposing practical guidelines to optimize health promoting residential greenery to the benefit of all.

2. Materials and methods

2.1. Study area

Our study focuses on the residential greenery of modernist housing complexes, similar to those in almost all Central European cities, that are home to two thirds of the Berlin population. We took a closer look at the residential greenery at eight study sites in the most disadvantaged residential neighborhoods of Berlin, Germany, areas with high noise and air pollution, high bio-climatic stress, low social status indexes and low access to green spaces, identified on the basis of the Environmental Justice Map of Berlin (SenStadtUm (39); see details in Battisti et al. (40) and Supplementary Figure S1). The social status index combines indicators covering percentage of beneficiaries of social welfare, inhabitants with migration background, old-age poverty, child poverty, and single-parent households (39). Two of the sites are in East Berlin and can be categorized as real estates with post-socialist heritage (Berlin Mitte and Marzahn).

The block developments from the years 1870–1918 are (almost) closed, mostly 4–6 storeys, with a front building, side wings and rear building (Figure 1). Their backyards are dominated by concrete courtyard areas, and some feature isolated flower beds, shrubs or single trees.

FIGURE 1
Residential greenery of dense block-edge development of the Wilhelminian era examples from Berlin-Wedding and Neukölln (SenStadtWo, Orthofotos August 2020; Geoportal Berlin; Photos: *HealthyLiving*).

The reform-oriented perimeter block developments, 3–4 storey (almost) closed structures, were built between the 1920s and the 1940s. They feature larger inner courtyards, usually containing a lawn, sometimes garden plots and a few trees (Figure 2), and also some paved or concrete areas.

Row developments from the 1920s to the 1970s consist mostly of 4-storey rows of houses, often in a row, resulting in larger, elongated, interconnected open spaces (Figure 3). These are usually in the form of lawns with selective bushes and trees.

The high-rise buildings/prefabricated buildings of the 1960s to the 1980s are rows or point houses with different block or row constructions, usually over 6 storeys high (Figure 4). Most of the undeveloped areas are covered by lawns with some trees or shrubs and ornamental gardens with access paths, and parts concreted over as parking lots.

Today the residential greenery of multistorey modernist housing complexes originally designed in these different epochs do not share a common mode of landscape architecture. While woody species mapped in the residential greenery have a medium to high air filtration capacity, one to two thirds of the planted species have a high allergenic potential (34). All residential greeneries have common elements that support physical activities and related healthy lifestyles such as bike racks, benches, playgrounds, partially sealed parking lots and spaces for garbage containers. Nature-based solutions like bioswales, facade-attached greenery, atriums, fountains, or ponds are rare (34, 40).

2.2. Assessment of semi-public residential greenery of the modernist housing complexes

In order to capture the development potential of residential greenery for the integration of nature-based solutions, the area of settlement green space was calculated from the areas of the respective "urban structure types" of block development from the 1870s to 1940s, row development from the 1920s to 1970s, and high-rise buildings from the 1960s to 1980s that were predominantly prefabricated (i.e., Nos. 1, 2, 10, 72, 9, and 11; (39)), subtracting building forms and sealed surfaces, public green spaces, and playgrounds (41). The geodata were processed in QGIS v3.10.11-A (42).

2.3. Interviews on suggestions to improve residential greenery

In summer 2018 and 2021, we conducted 270 face-to-face interviews with residents at the eight study sites that represent the four main building types in Berlin. We collected basic information on demographic data, use and perception in closed questions (9) and, in an open-ended question analyzed using content analysis (43), suggestions to optimize benefits of the residential greenery on health and wellbeing, with a focus on nature-based solutions. Based on the

FIGURE 2
Residential greenery of reform-oriented perimeter block development with courtyards in Berlin-Reinickendorf (SenStadtWo, Orthofotos August 2020; Geoportal Berlin; Photos: *HealthyLiving*).

responses, statements were categorized on content and keywords. One category of people referred to (green) nature-based solutions (e.g., green; trees; flowerbeds; lawns; greenspace; green facades; green roofs), another category explicitly mentioned biodiversity related aspects and/or benefits of nature-based solutions (e.g., meadows instead of lawns; a third mentioned concrete plant or animal species, wilderness, biodiversity), a fourth did not mention nature-based solutions (Supplementary Table S1). Each individual keyword was assigned to one or more of the categories and so transformed into a variable. Respondents were first categorised as "Green Supporters", "Biodiversity Friends" and "Others", and second as respondents claiming quantitative, and/or qualitative enhancement of residential greenery, and "Others". We developed categories based on the respondents' statements on the open question on suggestions with similar content regarding green, biodiversity friendly or other solutions that were mapped to a category (Supplementary Table S1). The survey data were analyzed using R (44) to test cross-tabulated ordinal data for independence with the chi-squared test.

2.4. Co-creation workshops on re-design of residential greenery

The co-creation workshops were piloted in the district of Marzahn-Hellersdorf in a neighborhood with prefabricated buildings of the 1980s, where a new housing construction project is also leading to redesign of existing residential greenery. In total about 50 attendants participated in three different discussion rounds, including residents and relevant local stakeholders.

A first workshop was set up in May 2019 (Figures 5A–D), bringing together the target groups of residents, the housing company, a local NGO, gardeners of a local community garden, employees of the municipality administration and scientific researchers. After a short introduction to the background (including previous survey results; (35)), a world cafe format was used to discuss necessities and obstacles of redesigning the residential greenery and to establish different interests and needs of the participants. The three main topics were: (A) Envision a successful participation process for redesigning residential greenery; (B) What does your residential greenery ideally look like?; (C) Dealing with contrasting interests. The participants had about 20 min per discussion round. Ideas, suggestions and critical comments were collected on blank posters. The answers were then categorized in six different clusters (communication and information, coordination, design suggestions and needs, responsibility, biodiversity, and concerns; see Supplementary Table S1).

A second workshop was held on October 3rd, 2019—a public holiday—integrated into the garden autumn celebration of the local community garden (Figure 5E) in order to address, in particular, the local residents in a more informal atmosphere than in the previous workshop. Presenting the results from the first participation event was used to get the resident's attention, to stimulate and deepen the discussion in personal conversations, and to lower the barrier for

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FIGURE 3
Residential greenery of row development with courtyards, examples from Berlin-Mitte, Charlottenburg and Spandau (SenStadtWo, Orthofotos August 2020; Geoportal Berlin; Photos: *HealthyLiving*).

residents to make contact and to discuss possible improvements for the residential greenery.

2.5. Developing a practical guideline

For the drafting of our practical guideline, we adapted the following steps proposed by De Montis et al. (45): (i) analysis of status quo of residential greenery, (ii) context specific SWOT analysis to identify needs and define objectives for actions, (iii) consistency check with other guidelines and strategies in place, (iv) drafting of guidelines tailored to the specific geographical and institutional context, (v) presentation of the draft to acquire views and comments from interested parties, and (vi) verification on the final contents of the GI guidelines with representatives of housing companies, landscape architects and other potential users. Results of the steps i–iii have been published in several papers [e.g., (21, 34, 35, 40, 46, 47)], and the results of step v are presented here and in Mohr-Stockinger (46). Step vi is ongoing.

3. Results

While public green covers about 53.8 million m^2, of which 31.6 million m^2 are public parks (Figure 6A; Geoportal Berlin), residential green covers an undeveloped area of 43.6 million m^2, with area sizes varying from areas of less than a 100 m^2 between buildings to several hectares of green space with scattered buildings, with a median of about 7,400 m^2 (Figure 6B). Soil is partially sealed through passages, parking lots and paved areas for garbage containers and ranges between 10% and 60% (Figure 7).

3.1. Green or biodiverse, more or better?

In order to define residents' demands, we asked a total of 270 people for suggestions to optimize health related benefits of their residential greenery. Of the respondents, 43% were male and 57% female, half were between 31 and 60 years old, and had, on average, lived 17 years in their respective neighborhood (see details in Säumel and Sanft (9)). Overall, residents were generally very satisfied with the greening of their living environment and, regardless of the neighborhoods' structural differences, half did not suggest any improvements regarding nature-based solutions within the residential green space (Table 1), while 40% expressed the need for enhanced greening, and about 16% mentioned measures to enhance biodiversity friendliness. In addition, around 20% suggested spatial or numerical expansion of green elements such as more trees or larger green areas, and nearly 40% demanded a

FIGURE 4
Residential greenery of large housing estates and high-rise buildings in Berlin Marzahn and Gropiusstadt (SenStadtWo, Orthofotos August 2020; Geoportal Berlin; Photos: *HealthyLiving*).

qualitative improvement of green structures. The need for measures to qualitatively enhance residential greenery was more often expressed in the dense and closed block-edge developments of the Wilheminian era. Residents of the large housing estates with towers and high-rise buildings from the 1960s to 1980s most often asked for more green, while residents of the parallel and free row development within landscaped residential greeneries of the 1920s–1970s asked more often for biodiversity friendly measures.

There were also differences between neighborhoods, independent of the general building structures or the location of a neighborhood along an urban–rural gradient. For example, residents of the inner city Ideal-passage in Berlin/Neukölln and Alte Jacob Str. in Berlin/Mitte more often suggested greening measures, and in the latter neighborhood the need for biodiversity friendly measures were also more often mentioned compared to other inner city block edge or row developments (Table 1 and Supplementary Table S2). Quantitative development of the residential greenery was especially suggested in the dense block edge developments and in the neighborhoods of East Berlin (Alte Jacob Str. and Marzahn), whereas qualitative enhancements were mentioned most in the Sprengelkiez in Berlin/Wedding and Alte Jacob Str. in Berlin/Mitte.

3.2. Co-creating healthy residential greenery

Although three different topics were discussed in the workshops (Supplementary Table S3), similar aspects arose in all discussion rounds. These are summarized next.

3.2.1. Envisioning a successful participation process

Nearly half of the comments mentioned enhanced communication measures to inform neighbors about the process. One third wanted to take more responsibility for the residential greenery, including joint maintenance, training for residents, and its integration into the rental contracts. The main goal of co-creation is to build up a stronger community within the neighborhood, so networking and communication are essential. The residential greenery can then be designed and divided into smaller sections, facilitating neighbors taking responsibility for plot maintenance. Neighbor groups, consist of a housing unit, could meet, discuss problems and solutions and distribute tasks and do voluntary work. Neighbors are willing to coordinate design and management themselves. Time capacity and flexibility of neighbors need to be considered. Some neighbors

FIGURE 5
Impressions from the co-creation workshops with residents and relevant actors in Berlin Marzahn-Hellersdorf (**(A–E)**; Photos: Frederike Büttner). Target group specific, simple and user-friendly: Screenshots from the guideline brochure for implementation of nature-based solutions (in German) for object planners, housing companies and residents (**(F)**; see Guidelines in the Supplementary material).

mentioned "Subbotniks" that were common when the neighborhood was built in times of the GDR.[1] The attendees believe such self-growing structures can also function today, starting from smaller core groups and facilitated by the housing companies. A column in the housing newsletter could motivate and mobilize the residents to participate. To ensure the equal participation of all willing to get involved, the co-creation process and communication between neighbors and housing companies should be moderated by a coordinator. To get from the ideas and brainstorming to a successful redesign of the residential greenery, communication needs to be clear and honest from the beginning, including doubts and problems. Conflicts of interests can be discussed in an open dialog within the housing units to find a solution where everybody feels involved, including the quieter ones. The attendees proposed that design workshops could help better understanding and to illustrate usage possibilities to support the decisions made. The redesigned areas are designed, managed and maintained by the residents, with reliable support from the housing company providing technical support and water supply. Semi-annual seminars, by experts on gardening topics, could help deepen residents' knowledge and increase their confidence to maintain a tenants' yard.

3.2.2. Your ideal residential greenery

Attendees evaluated the current design of the residential greenery as very simple, and the participation by the local residents as low. Many clearly expressed their appreciation for the residential greenery and the motivation to help in redesigning the area. They proposed higher appreciation of the residential greenery by the housing companies and a focus on their personal needs as well as more education on the significance of the green and its unused potential. A third of the comments demonstrate willingness to actively take responsibility, asking for tenant plots and more individual designs. Small scale pilots could provide first practice examples. Having a direct contact person and generally lowering the barriers to interact with the housing company was also often mentioned. The residents ask for more structured areas with sections such as protected, cozy lounges and meditative places with elements of tranquility that invite lingering, as well as space for gardening and their own designs. Neighbors want more individual solutions for the different locations, not "an easy-care planting plan" without accessing the areas and consulting the local residents. Every fifth comment was related to biodiversity aspects (e.g., a "wilder vegetation" instead of plain lawns; implementation of wildflower meadows, more individual planting plans, fruit trees and rooftop gardens). The residents miss opportunities to garden and expressed special interest in taking responsibility for small plots of 10 m^2, which they would plant and design independently and are willing to maintain. Better participation promotes the identification of the residents with their place of living

1 GDR: German Democratic Republic (1949–1990). "Subbotnik" meant doing something for the community on a Saturday (Russian: Subbota). Voluntary work in the housing communities included gardening, care and maintenance of residential greenery. Particularly in the spring, active neighbors worked voluntarily to enhance their residential greenery, sports facilities, playgrounds for schools (e.g., removing garbage, planting trees, shrubs and flowers, painted facades, or renovated club rooms). The housing administration provided materials (e.g., plants, tools, and paint), and people met for a barbecue after work. There was no obligation to participate but it was attractive for neighbors to enhance their social network participating in these activities that at the same time also enhanced the attractivity of the living environment on their doorstep.

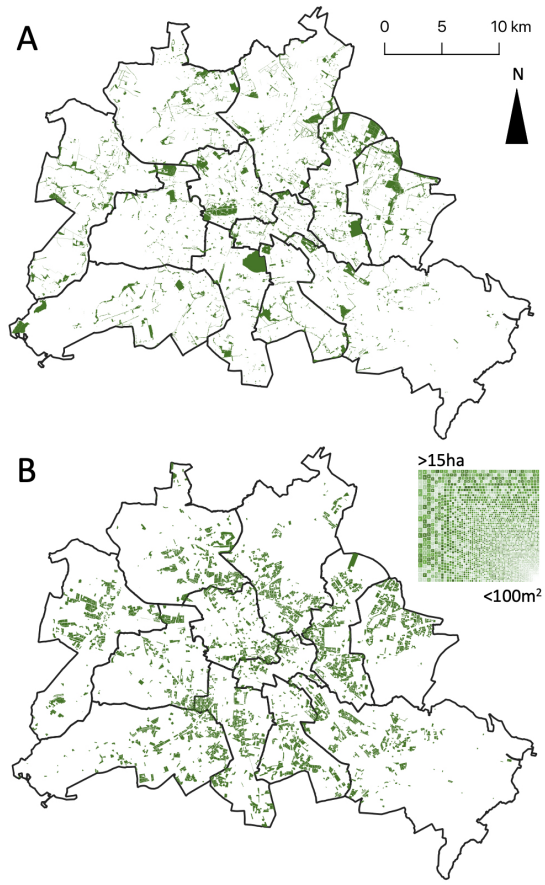

FIGURE 6
Public green space and playgrounds **(A)** and semi-public residential greenery of modernist housing complexes consisting of diverse patch sizes **(B)** of Berlin, Germany. District borders of Berlin are given.

and less vandalism is expected if many people feel responsible and associated. Still, the housing companies, as the owner of the sites, need to keep in contact and should be easily and informally accessible in case of questions and problems. The attendees recommended a person in charge, who attends the tenants' meetings occasionally.

3.2.3. How can contrasting demands of neighbors coexist?

The majority suggested measures like zoning, alternating use and multifunctionality. Individual solutions for the different areas and sections of the residential greenery provide opportunities to take the diverse needs into account. Enhanced coordination and exchange yard celebration and community spaces help to reduce anonymity, prevent conflicts and improve the communication within the neighbors and with the housing companies, and so build trust. In this round, residents also asked to be involved in the design of their residential greenery. With smaller, self-maintained plots, alternating usage is also possible. The residents wish to make decisions themselves about the seedlings, plant selection and to design the plots provided. Additional co-operation with neighbor's green spaces, for example watering during holiday season, will lower burdens. The attendees requested that housing companies provide facilities for gardening activities such as a water supply in the yards. Building greening, structural elements and different colors can redirect the gaze away from the lawn as well. They argued that greenery as a spacing element will then slowly lose its relevance. A smart design shaping small, individual spaces and zoning enables the coexistence of active and passive use side by side and allows adjustments to the different needs. Barrier-free access to the area should be ensured. The participants envisioned a separation of areas with active and passive usage and suggested linking the apartment size and the design of the greenery in new building projects, which enable flexible floor plans and possible adaptation to changing living conditions.

3.3. Practical guideline and portfolio of NBS for different building structure types

The guideline to optimize health promoting residential greenery (Figures 5G,H; in German and English translation in the Supplementary material) informs housing companies and their tenants by including a portfolio of different nature-based solutions suitable for the four most common building types in Central European cities and a decision matrix. Each measure is described and its health-related potentials highlighted (Tables 2, 3; see details in the Supplementary material).

4. Discussion

Even if the saying that crises always represent an opportunity has been overused in recent years, times of crisis do facilitate social innovation and the revision of what is owned and what is needed. Crisis-driven new discoveries, claims and encounters within urban green have been reported for the Covid-19 crisis (9, 48, 49, 50). Our results underline that the provision of cultural and health relevant ecosystems services by urban green was increasingly appreciated, especially for the green of our living surroundings, which is known as residential greenery. In both interviews and co-creation workshops, residents called for multifunctional and structurally rich green spaces near their homes (Table 1). Views out of the apartments' window on residential green are of great importance especially during lockdowns and for less mobile people (47). Balconies became a green oasis (51) and a space to communicate with neighbors during lockdowns (52, 53). The crisis fostered appropriation of residential greenery for uses such as meeting neighbors or doing sports, and the spectrum of residents' requirements expanded significantly to active use settings (9) as the green on the doorstep became a crucial refugia for neighbors.

Half of the respondents asked for qualitative and/or quantitative enhancement, with biodiversity-friendliness a crucial feature in their "ideal" residential greenery (Table 1). This suggests growing awareness and nature connectedness, as these topics have not been mentioned often in previous studies (35). However, the interrelatedness of actual or perceived biodiversity of urban green and influencing parameters like species literacy, recreational and health benefits, visitations rates and nature connectedness is still poorly understood, and research findings are inconsistent (54, 55). Biodiversity management within urban green and blue needs to consider multiple scales, negotiated among various actors and accounting for a myriad of influencing factors (56). Biodiversity becomes a topic also for communal housing companies at least in pilots and when it is supported by external

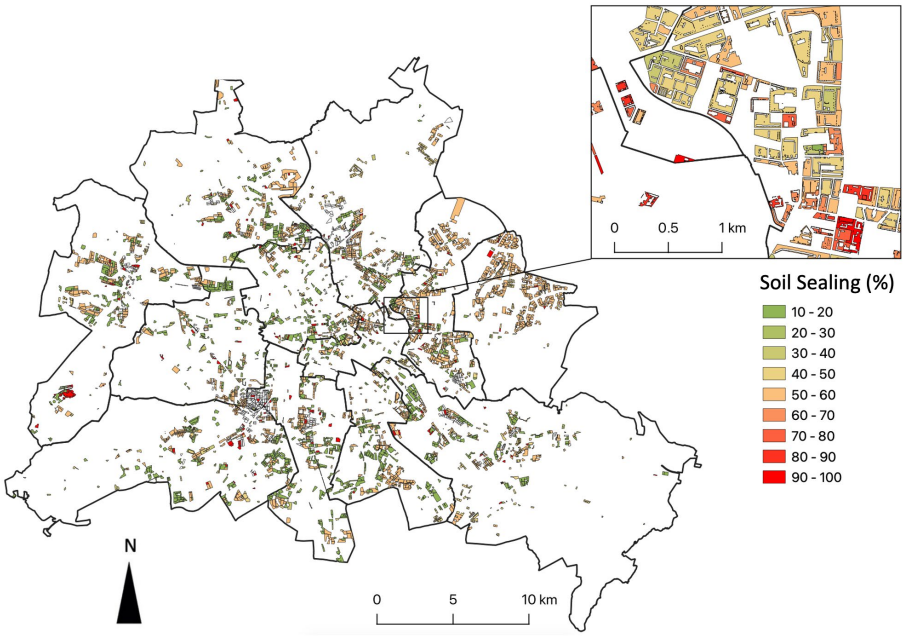

FIGURE 7
Soil sealing in the semi-public residential greenery of modernist housing complexes of Berlin, Germany. District borders are given.

TABLE 1 Number and percentage of residents suggesting an enhancement of residential greenery regarding greener and/or biodiverse residential greenery (A) or regarding quantitative and/or qualitative development (B).

		A: Green or biodiverse?			B: More or better?		
	All	Green supporters	Biodiversity friends	Others	Quantitative	Qualitative	Others
N	270	106	43	158	56	106	142
%	100	39	16	58	21	39	53
Comparison between structural types							
χ^2		2.1	0.9	0.6	0.6	1.4	0.8
df		2	2	2	2	2	2
p		0.341	0.627	0.740	0.736	0.442	0.665
Comparison between neighborhoods							
χ^2		22.1	27.9	9.8	33.2	20.8	13.0
df		7	7	7	7	7	7
p		0.002	<0.001	0.201	<0.001	0.004	0.072

Some respondents are classified in both categories on the basis of the keywords (see Supplementary Table S1). "Others" did not mention any keywords. Comparison between block edge development (Block), row development (Row) and high-rise buildings (High). Chi-squared test, df and *p*-values are given. See full table in Supplementary Table S2.

funding (57). Planners and landscape gardeners are learning biodiversity-friendly management techniques, dealing with water scarcity or other aesthetics beyond the English lawn. Our results show that residents can be allies and are key actors to be involved in biodiversity-friendly (re)design and management. However, green washing and green branding using nature-based solutions is a widespread phenomenon, especially when developers refer to ecological values and greenery in marketing campaigns (58, 59).

Moreover, our results from Marzahn-Hellersdorf support findings that large housing estates from the socialist era represent relative social stability and offer affordable housing as it has reported for other post-socialist cities (24). In addition, the Berlin housing market is currently under great strain due to a combination of a rising population, a lack of new residential construction and a growing real estate speculation. Rising rents for new rental contracts in the last decade tie tenants to existing rental agreements. Thus, we overserved long residential times in the studied neighborhoods in average of about 17 years (9). In addition to great investments of the housing companies to change the stigmatized neighborhood images, apartments in formerly not so attractive housing estates (also those constructed in socialist times) became attractive for the middle class.

Although, inclusive and empowering participation schemes such as co-creation have been proposed to prevent conflicts and

TABLE 2 List of recommendations for implementation of various greening measures in relation to building structures block development (A) and reform-oriented perimeter block development (B) (see detailed descriptions health-relevant ecosystem services provided by these measures in the Supplementary material).

NBS	Block development	Reform-oriented perimeter block development
Green roof (GR)	Roof pitch and statics of the building often do not allow GR. Pot planting on existing terraces is preferable.*	
Façade greening (FG)	FG is highly recommended, due to a high degree of sealing and the small proportion of open spaces close to the ground. Give preference to climbing aids for ground-based systems. If the structure is porous, take care of the root and tip growth of the tendril and cut it back regularly.*	
Meadows & wild shrubs (MS)	Paved or concrete inner courtyards often do not allow for lawns. The height of the building and the size of the courtyard determine the incidence of light. Wild perennials can be grown in tubs or raised beds and can be integrated into every yard.	Depending on the size of the yard and the degree of sealing, MS can be realized. Note the incidence of light and plant wild perennials. If there is not enough free space, place raised beds or tubs in sun-exposed areas.
Open space (OS)	The OS design depends on the size of the yard and the demands of the residents. If there are children, sandboxes and swings can be installed in the yard, regardless of the degree of sealing. Raised beds invite to do gardening, while benches and tables lure residents outside. Even in a small space, create an opportunity for residents to stay and spend their free time together.	
Bodies of water (BW)	Although BW are difficult to integrate and take up a lot of space, they are indispensable for city animals. Provide bird baths.	In larger courtyards, small BW can be easily integrated. If not possible, create other water sources for city animals in the form of bird baths.
Trees, shrubs, hedges (TSH)	TSH requires an area of at least 5 m^2 that is free of sealing, but 6 m^2 is better according to DIN 18916. Note the incidence of light and possible shading from low-lying apartments during the growing season. Information on soil quality should inform species selection. With partially sealed floors, shrubs are an alternative to large trees. Structure the yard by lining borders and parking spaces. If there is a lack of space, plant shrubs in larger containers.	A larger open space means TS can be easily integrated into perimeter block developments. Pay attention to possible shading of the apartments below and a minimum distance to the building. Line parking spaces, flower beds and verges with shrubs to increase the amount of greenery.

*Note monument protection regulations that might be in place.

TABLE 3 List of recommendations for implementation of various greening measures in relation to building structures row settlement (C) and large housing estates (D) (see detailed descriptions health-relevant ecosystem services provided by these measures in the Supplementary material).

NBS	Row settlement	Large housing estates
Green roof (GR)	If static requirements are met, intensive or extensive roof greening measures are suitable. If there are flat roofs, raised beds can be added.*	Most of the buildings of these structures are best suited for green roof measures. Supplemented by raised beds, they become the new ecological focal point of the residential unit for residents.*
Facade greening (FG)	The same applies: facade greening is a simple option for integrating greenery into the living environment and should always be considered. Self-climbing plants and plants with climbing aids make rows of buildings green. If the building structure allows it, wall-mounted systems can be integrated.*	Due to the better building fabric, more modern buildings are well suited for wall-mounted systems. If this cannot be implemented for financial or planning reasons, ground-based systems are highly recommended.*
Meadows & wild shrubs (MS)	Green spaces between the rows of buildings ensure good incidence of light and are suitable for wild flowers and perennials. Create large or small wildflower beds and complement them with raised beds.	Larger open spaces enable the creation of a diverse wildflower meadow. Ensure that this is step-protected under certain circumstances by releasing other sub-areas.
Open space design (OSD)	Since row developments often include larger units, the diversity of residents is particularly high. Multi-generation parks are particularly recommended here.	The population density and the associated diversity can be served by a multifaceted range of design elements. Create social spaces through seating, multi-generation parks and the joint management of, e.g., vegetable beds.
Bodies of water (BW)	If there is enough space between the rows of buildings, several smaller bodies of water can be integrated in the form of fountains or ponds.	Bodies of water create an ecological and social hotspot on larger open spaces and should therefore be preferred.
Trees, shrubs, hedges (TSH)	Low trees can be planted several times between the rows of houses and can be supplemented by large trees. Fruit trees are pollinator friendly and provide residents with a variety of choices over the long term. Shrubs and hedges create structure between the rows of buildings and can frame paths and parking spaces. The combination of different species is of ecological advantage here.	Both large and small trees can be accommodated on larger systems. Plant a variety of fruit trees that residents of all ages will enjoy, and optionally incorporate maintenance into an urban gardening project. Integrate shrubs and natural hedges as structuring elements. Planting different species creates diversity.

*Note monument protection regulations that might be in place.

FIGURE 8
One of the most beautiful paths to ourselves leads through the garden. Tenants and community gardening as crucial element to enhance social cohesion, health and wellbeing in the residential greenery in different building types of Berlin, Germany (Photos: *HealthyLiving*).

counteract green gentrification (60), they are still rare. Moreover, interventions aiming to reduce environmental injustices in fact have also deepened existing ones, failing to effectively and meaningfully involve the affected people in an inclusive manner (61). The urban farming and edible city movement demonstrated that edible nature-based solutions such as vegetable gardens on our doorstep (Figure 8) foster the development of socially inclusive, biodiversity friendly, resilient and healthy cities (62). Thus, community gardens became heterotopias and multilayered places in the post-socialist Zagreb satisfying diverse needs of the residents (63). Community gardens have been also used as strategic tools for neighborhood management by administrations in different Hungarian cities (64) or emerged from bottom-up movements fostering urban commons and food citizenship, e.g., in Cologne (65), Rotterdam (66) or in Berlin (67). Nature-based solutions are implemented using diverse governance arrangements from administration-led to citizens-led modes (38, 68) and extending networks from single productive gardens within a neighborhood to regional scales (35). We provide evidence that the residents of neighborhoods classified as suffering environmental injustice are ready to set aside being "eternal complainers"[2] about their living environment and become more involved in the design, implementation, and maintenance (Table 1). Consequently, urban planners, neighborhood managers, housing companies and, last but not least, neighbors should join forces to unlock the potential of residential green as an effective measure of preventive medicine (69). While our evaluation of the semi-public open and green spaces attached to multi-story housing complexes (Figures 6, 7) is only a first approximation that needs to be explored in more detail, it demonstrates the enormous development potential that lies on our doorstep and that can be optimized for the benefit of all.

We have developed a guideline (46), proposed and tested an optimization loop to strategically foster health promoting ecosystem services of residential greenery (Figure 9). The process has different starting points and can be initiated by different actors, e.g., residents can articulate their demands (see Section 2.3) and initiate co-creation processes in a bottom-up manner, especially to discuss conflicting demands and agree on solutions. Guidelines for implementation of nature-based solutions can provide examples and best practices to inspire and inform the process (see Sections 2.4. and 3.3). Our guideline highlights that some interventions are more suitable for certain building structures. As with residents' suggestions, however, there is no universal solution, even for neighborhoods with similar structural or socioeconomic parameters, because the surrounding urban fabric and its dynamics determine and alter the environmental and social impacts of neighborhoods on different resident groups, and thus on their needs. Neighborhoods and even parts of them, such as blocks or backyards of housing developments, need tailor-made solutions and social-ecological innovations to successfully foster stakeholder engagement, local stewardship and inclusiveness (68, 70, 71). The optimization process can also be initiated by housing companies and local administrations in a

2 The phrase about needing to stop being "perpetual complainers" was often used in the workshops by local stakeholders, including residents, in a very positive sense of being active participants in shaping their neighborhoods rather than remaining in a passive role.

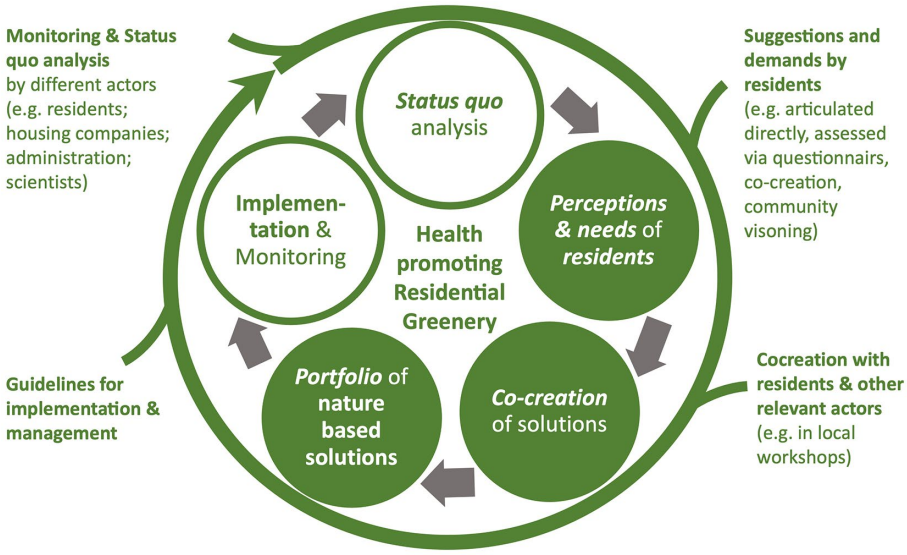

FIGURE 9
Optimization loop toward health promoting residential greenery.

top-down manner as a response of identified problems and challenges based on public databases on environmental justice, health or social indicators [e.g., (34, 40)] or in self-research by residents in a bottom-up process.

5. Conclusion

Residential greenery is an important and, to date, an under-exploited health resource in the context of the diverse dimensions of individual and public health and wellbeing. Its multifunctionality, accessibility and immediate use by neighbors in everyday life allows it to directly and effectively address hard-to-reach target groups. Our results show that planners and administrators are preaching to the choir that neighbors are already highly motivated to actively participate in the creation of locally adapted solutions and to take responsibility in health-promoting optimization of residential green spaces. Furthermore, there is evidence that biodiversity-friendly interventions are increasingly in demand, supporting planetary health. Designing an inclusive and actively usable "green living room" will not only narrow the gap in times of pandemics and reconnect neighbors as the "social fabric" of our neighborhoods, but also unlock the potential of residential greenery as a "sleeping giant of urban green" that can catalyze biodiversity-friendly urban renewal in quality and quantity. We emphasize the critical role of residential green space in addressing inequities in urban habitat and the need to preserve, restore, and redesign residential green space to improve the health and resilience of our cities.

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.

Ethics statement

Ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. Written informed consent for participation was not required for this study in accordance with the national legislation and the institutional requirements.

Author contributions

SM-S developed the guideline. FB developed and analyzed the co-creation workshops. SS and IS performed and analyzed the survey. RR created the maps. IS drafted the first version of the manuscript and received the funding. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1175605/full#supplementary-material

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Exploring Restrictions to use of community greenways for physical activity through structural equation modeling

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Public health problems caused by rapid urbanization have attracted increasing amounts of attention. Existing studies show that improving the frequency and duration of physical activity among urban residents can effectively reduce their disease risk. A community greenway, as a green space for public activity directly serving community residents, is one of the best spatial place for bringing health benefits to people. Although the scale and scope of greenway construction have been increasing in recent years, the utilization rate of some greenways is not high for various reasons, restricting the extent to which people engage in healthy physical activities in greenway spaces. In this study, the greenway of Nancheng Community in Wenjiang District, Chengdu city, China was selected as the object of study, and structural equation modeling was conducted to explore the objective environmental factors and individual characteristics acting as barriers to use of the community greenway by the population for physical activity. The results show that user experience, the greenway landscape, and safety and accessibility are important factors that restrict people's willingness engage in physical activity in the community greenway environment. The results of this study provide a direction for further consideration of ways to enhance people's willingness to make use of greenways for physical activity, and further provide a theoretical basis for the healthy design and transformation of community greenway spaces.

KEYWORDS

community greenway, physical activity, restriction, structural equation modeling, landscape characteristics

1. Introduction

Rapid urbanization has brought an increasing number of public health problems to the attention of the public and has increased health risks among the population in several ways, especially in the areas of mental illness (1, 2), chronic diseases such as cardiovascular disease (3, 4), and general health (5–7). Empirical studies of environmental health and public health indicate that increasing the frequency and duration of physical activity can effectively reduce the risk of these diseases among urban residents. For example, increasing physical activity as a form of leisure can improve the health of the population (8), enhance physical and mental health (9), and also help to reduce stress, regulate emotions, and improve cognition (10–13).

Green open space is an important feature of a healthy outdoor living environment and an important type of space for the promotion of people's participation in physical activity. Research

has found that the number of parks in the vicinity of an area of residence is directly proportional to the intensity of physical activity engaged in by its population, and the provision of different types of environment within a park can support different types and levels of physical activity (14). Residents' personal attributes also play a moderating role in the relationship between green space and recreational physical activity (15). Some scholars have also focused on the relationship of green public space with physical activity among different groups: for example, community parks and trail length are positive predictors of increased physical activity among older adults (16), while street greenways also result in increased physical activity among older adult patients and in the creation of a healthy aging environment (17).

As an indispensable linear form of green open space and a component of an urban green space system (18, 19), greenways provide residents with a suitable space for slow walking and can be used as sports venues (20, 21); they therefore have the health-related effects of relieving mental pressure, increasing physical activity, and promoting social interaction. By creating an ecologically friendly environment, greenways can bring people closer to nature to relieve mental stress (22, 23), provide a walking environment for the promotion of physical activities such as walking, cycling, and stretching (24, 25), and form a network of green channels to connect different communities, thereby stimulating public interaction (26). According to empirical research, the above benefits are more evident in the case of greenways connecting neighboring communities (27, 28), which can positively impact and restore the mental state and physiological capabilities of residents (29), especially those of older adults in the community (30, 31). Greenways connecting neighboring communities affect the amount of exercise taken by residents, mainly through the provision of a pedestrian environment enabling community residents to take control of their engagement in physical activity; this benefits the amount of exercise they take, which in turn improves the health of residents (32). Thus, the features of greenways in the built environment can positively affect the intensity of residents' physical activity (33).

Although the scale and scope of greenway construction have been increasing in recent years, the utilization rate of some greenways in reality is not high, as a result of many subjective or objective restrictions limiting individuals' participation in healthy physical activities on the greenway space; this reduces the quality of recreation services provided by the greenway. Among these restrictions, intrapersonal, interpersonal, and structural restrictions all affect people's use of greenways for recreational activities (34), and generally, these three factors impose decreasing levels of constraint, in the order of mention (35). Previous studies have proved that preference, time, travel costs, and geographical distance are the main factors restricting recreational activities in urban green spaces (36), but few researchers have discussed the factors specific to community greenways regarding the willingness of people to engage in physical activity.

Therefore, on the basis of a literature review and questionnaire-based survey, the aim of this study was to construct a model of the factors acting as restrictions to the use of the community greenway for physical activity by the population. Taking the greenway of Nancheng Community in Wenjiang District of Chengdu as the object of this social investigation, structural equation modeling was used to verify the variables identified, with the aim of exploring the objective environmental factors and individual characteristics that act as restrictions to use of the community greenway for physical activity among the population, and of exploring the strength of each influencing factor (Figure 1).

2. Methods

2.1. Site selection

The South City Community Greenway in Wenjiang District, Chengdu, China was selected as the research object for this study. This 87-km-long greenway connects schools, metro stations, bus stops, hospitals, and other public services constituting a 15-min living circle, providing a very good spatial place and a high-quality space for green and low-carbon travel, grocery shopping, leisure and sports, and neighborhood interaction for residents in the surrounding area; it is one of the most frequently used greenways in Chengdu. A total of 20 residential areas, clusters, and compounds within 1 km of the South City Community Greenway Station and its surrounding areas were selected for inclusion in this study (Figure 2).

2.2. Design of the questionnaire

2.2.1. Initial selection of items

Following extensive reading and collation of literature related to greenways and constraints on them, 14 articles with strong relevance to the content of this study were identified. In-depth interpretation and analysis of these was carried out; relevant elements mentioned in the literature pertaining to the characteristics of greenways and personal subjective factors that restrict the willingness of the public to make use of them were extracted, and an initial set of factors constraining public use of community greenways was constructed (Table 1). This initial selection of factors included five factor dimensions as latent constructs: greenway landscape (GL), service facilities (SF), personal and interpersonal factors (PH), experience of use (UE), and accessibility and safety (SA). Each dimension contained several specific items, for a total of 32 observed variables. The five latent variables could not be measured through direct observation in practice, but the observed variables could be; therefore, the latent constructs in the factor system were measured via the corresponding observed variables.

2.2.2. Optimization of items

Through interviews with people using the greenway and relevant experts, items were added to and removed from the set of potential influencing factors was added, items were categorized, and the latent variable of personal and interpersonal factors (PH) was added. On the basis of the initial set of items for evaluation, the "Questionnaire on Constraints on Physical Activity Among Community Greenway Users" was developed to optimize measurement of the relevant items, taking into account the purpose of this study. Responses were given on a Likert scale, with respondents indicating the strength of each of the barriers as one of five levels: no effect, weak effect, average effect, strong effect, or very strong effect. Each of the 34 items was evaluated separately. The optimized form of the questionnaire was finally established as shown in Table 2, consisting of 6 latent variables and 34 observed variables (Table 2).

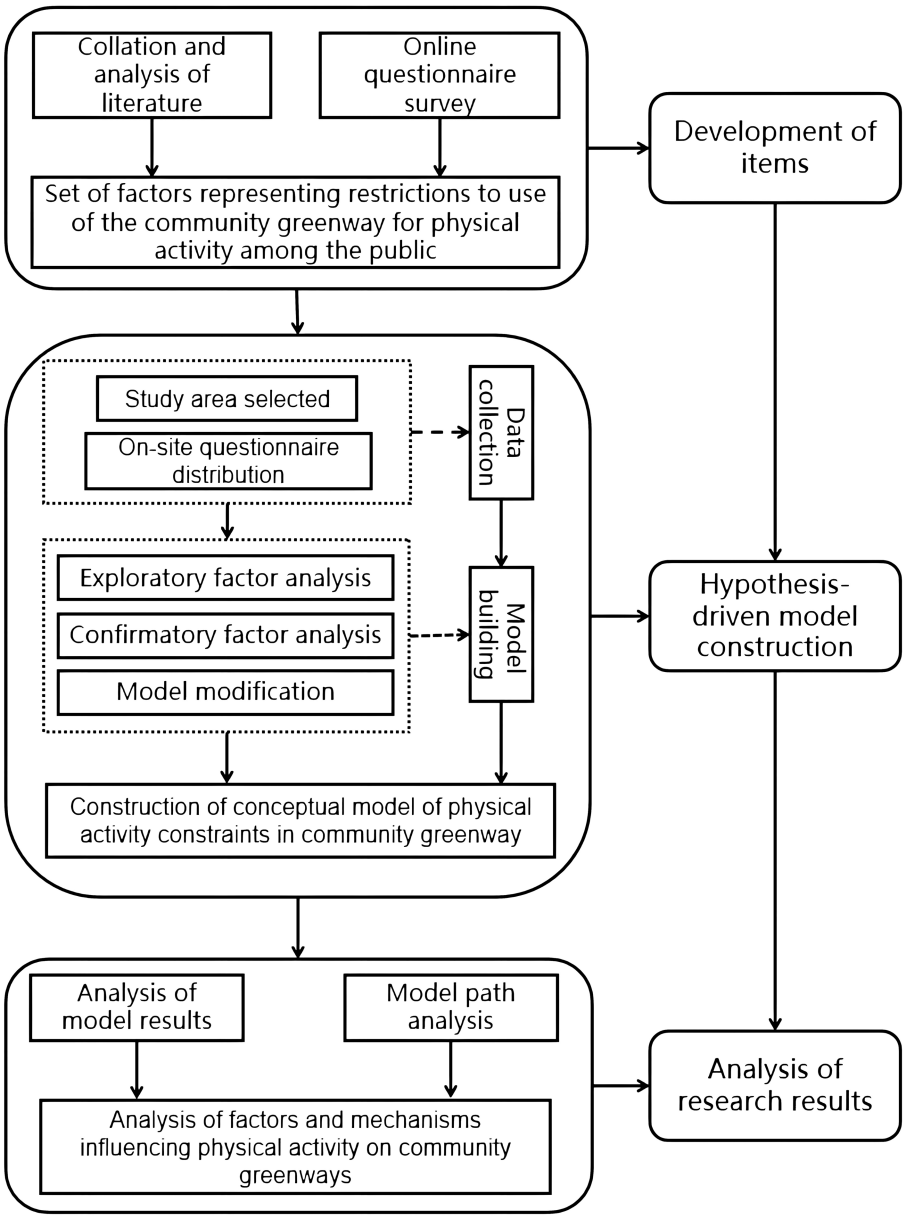

FIGURE 1
Flow chart for this study of restrictions to use of community greenways by the public for physical activities.

2.3. Procedure

The survey was completed between October and December of 2021 by a random sample of participants. For some participants who encountered difficulties in reading and filling out the questionnaire, the survey was administered in interview form and the participants were assisted in filling out their responses according to their opinions. A total of 350 questionnaires were distributed and 322 valid sets of responses were returned, for a valid return rate of 92%. As shown in Table 3, the participants represented a wide range of ages, education levels, and occupations, with a high degree of randomness, ensuring the reliability of the findings of the analysis.

2.4. Statistical analysis

Structural equation modeling (SEM) is a method for the construction, estimation, and testing of models of causal relationship; it is an extension of a variety of multivariate analysis techniques. A structural equation model contains both measurable observed variables and latent variables that cannot be directly observed. SEM can replace multiple regression, path analysis, factor analysis, covariance analysis, and other methods, and enables clear analysis of the effects of individual factors on the entire set of outcomes and the relationships between individual factors. Compared with traditional analysis methods, SEM enables explanation of as much of the variability as possible while providing an understanding of the

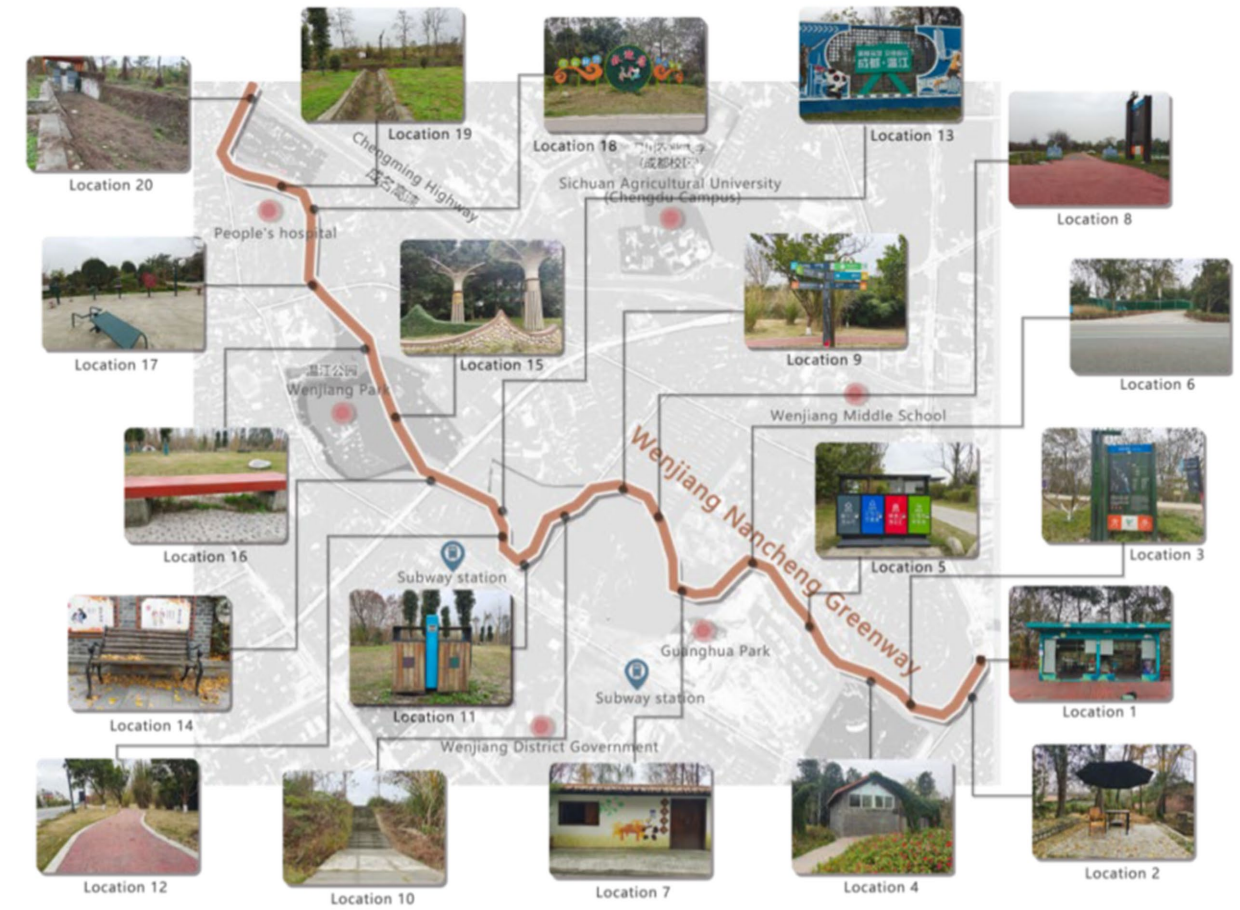

FIGURE 2
Schematic map of "green islands" in the southern district of Wenjiang.

covariant relationships between variables. There are two types of factor analysis within SEM: exploratory and confirmatory factor analysis. Exploratory factor analysis (EFA) is used to extract the structure of a set of data; CFA is used to validate hypotheses regarding observed and latent variables. In this study, EFA was first conducted to extract the main factors, and CFA was then used to validate the structure of the factors imposing constraints on physical activity on the greenway. On the basis of the structure arising from the CFA results, a model of barriers to physical activity on the community greenway is proposed.

3. Results

3.1. Construction of the conceptual model

3.1.1. Analysis of validity

Before exploratory factor analysis (EFA) is conducted, the data should first be analyzed for reliability and validity. The reliability of the valid data obtained in the present study was analyzed using SPSS 22.0. Cronbach's alpha coefficient for the standardized items was 0.953, indicating that the reliability of the questionnaire was high. The main tests of validity employed were Bartlett's test of sphericity and the KMO test. The results are shown in Table 4: the KMO value was 0.885 (KMO > 0.60), indicating that there was no significant difference in the correlation degree of each variable. For Bartlett's test of sphericity, $\chi^2 = 8533.125$, $p = 0.000$ ($p < 0.001$), indicating that the collected data for observed variables exhibited good intercorrelation and met the requirements for EFA analysis.

3.1.2. Exploratory factor analysis

Exploratory factor analysis (EFA) was first conducted to extract the dominant factors underlying restrictions to engagement in physical activity on the community greenway. Principal component analysis with varimax rotation was employed to determine the orthogonal factors, and factors with an eigenvalue greater than one were identified. As listed in Table 5, five factors were extracted based on EFA, accounting for approximately 66.26% of the total variance, with factor loadings ranging from 0.409 to 0.821. Common factor 1 represented "safety and accessibility," explaining 21.94% of the variance; common factor 2 represented "user experience," explaining 16.48% of the variance; common factor 3 represented "personal and interpersonal factors," explaining 11.53% of the variance; common factor 4 represented "services and facilities," explaining 9.09% of the variance; and common factor 5 represented "the greenway landscape," explaining 6.61% of the variance.

TABLE 1 Research on restrictions to physical activity on greenways.

Author	Research methods	Influencing factors
Keith et al. (37)	Descriptive analysis; regression analysis	Population characteristics; motivations for using the greenway; website preferences
Senes et al. (38)	Linear regression analysis	Landscape features; time; accessibility; density of roads; topography; historical and cultural interest
Akter et al. (39)	Correlation analysis Multiple linear regression analysis	Distance from home; barrier-free structures; landscape; lighting; drinking water and toilet facilities; maintenance standards; cleanliness; pavement width; indicating system; availability of parking lot
Mundet and Coenders (40)	Statistical analysis	Seating/rest area; drinking water facilities; conflict with motor vehicles; hygiene; topography; lavatory facilities; tree cover for shade
Coutts (41)	Statistical analysis	Density of population; degree of land-use diversity
Lindsey (42) Yang et al. (43)	Regression analysis. The GIS network analysis method	Visual permeability; intercommunity links; greening rate; land-use diversity; proportion of paved roads; density of facilities; continuity, accessibility, environmental comfort, spatial diversity
Qiaoqiao and Fengquang (44)	Correlation analysis Linear regression analysis	Transportation; natural environment; environmental hygiene
Jiang et al. (45)	Importance–Performance Analysis (IPA)	Ecological and cultural landscape; accessibility; infrastructure; management and maintenance services; surface conditions
Ye (46)	Analytic hierarchy process (AHP)analysis	Road network planning; design of scenic spots; design of green corridors; indicating system; parking facilities; recreation facilities; environmental sanitation facilities
Liu (47)	Factor analysis	Supporting facilities; service facilities; stage; greening environment; accessibility
Lu et al. (48)	Correlation analysis Factor analysis	Accessibility; environmental landscape
Zhanqiang et al. (49)	Linear regression analysis	Density of population; degree of land-use diversity; neighboring settlements
Lu and Lu (50)	Statistical analysis	Environmental sanitation facilities; safety facilities; accessibility

3.1.3. Confirmatory factor analysis

The common factors extracted via EFA were taken as latent variables, and the items falling within these were taken as the corresponding observed variables; a measurement model in the form of a structural equation model was thus established. In order to further test the reliability of the measurement model, confirmatory factor analysis (CFA) was carried out on the measurement model, including reliability analysis and validity analysis. The reliability analysis was conducted by computing Cronbach's α coefficient for each variable in the measurement model. As shown in Table 6, Cronbach's α coefficient was greater than 0.8 for each of the six latent variables, and the overall Cronbach's α coefficient was 0.953, indicating good reliability among the observed variables within each latent variable and among all latent variables, with good internal consistency.

In SEM, in order to test whether the model achieves a good fit, it is generally necessary to conduct statistical analysis by calculating the ratio of the chi-square statistic to the respective degrees of freedom (χ^2/DF), the RMSEA, the GFI, the CFI, and other indicators of fit. In this case, χ^2/DF = 6.699, and the standard criterion value is 1–3, meaning that this measure indicated that the goodness of fit was not up to standard; RMSEA = 0.673, and this value should be <0.08, also indicating that the goodness of fit was not up to the standard; and GFI and CFI were calculated to be 0.633 and 0.673, respectively, while these two indicators should be >0.9 (Table 7). Therefore, the indicators of goodness of fitness did not reach the standard criteria, indicating that the model fit was inadequate, and the model needed to be adjusted and corrected.

3.2. Construction of the structural equation model

The conceptual structural equation model describing the relationships between the six latent variables is shown in Figure 3. The main specific hypotheses relating to barriers to physical activity in community greenways are presented as follows:

> *H1*: Provision of services and facilities has a positive impact on the willingness of the population to engage in physical activity;
>
> *H2*: User experience has a positive impact on the willingness of the population to engage in physical activity;
>
> *H3*: The greenway landscape has a positive impact on the willingness of the population to engage in physical activity;
>
> *H4*: Safety and accessibility have a positive impact on the willingness of the population to engage in physical activity;
>
> *H5*: Personal and interpersonal factors have a positive impact on the willingness of the population to engage in physical activity.

TABLE 2 Preliminary selection of items and variables for the model of barriers to peoples' use of the community greenway for physical activity.

Latent variables	Observed variables
Personal and interpersonal factors (PH)	My attitude toward fitness and sense of engagement (PH1)
	Attitudes of friends and family toward fitness (PH2)
	My psychological health (PH3)
	My physical health (PH4)
	Time occupied by work/family(PH5)
	Have worked together (PH 6)
Greenway landscape (GL)	Architectural style and shape of gardens (GL1)
	Logo esthetics (GL2)
	Planting of garden plants and shading effect (GL3)
Services and facilities (SF)	Point-of-sale setup (SF1)
	Provision of fitness and sports facilities (SF2)
	Installation and cleanliness of toilets and drinking fountains (SF3)
	Installation of streetlamps and other lighting (SF4)
Safety and accessibility (SA)	Presence of sharp bulges in the seats and other facilities (SA1)
	Absence of unsafe remote dead ends (SA2)
	Installation of guardrails in hazard zones (SA3)
	Motor vehicle parking (SA4)
	Blocking the condition of motor vehicle facilities (SA5)
	Surrounding traffic (SA6)
	Interference of pedestrians and bicycles with each other (SA7)
	Non-motor vehicle parking (SA8)
	Convenience of access (SA9)
User experience (UE)	Marker lines indicate the correct condition (UE1)
	Prominent positioning of marker lines(UE2)
	Convenience of sideway crossing (UE3)
	Signs and lines are simple and easy to understand (UE4)
	Legibility of jogging lanes (UE5)
	Barrier-free design (UE6)
	Connectivity of the greenway to attractions (UE7)
	Ease of crossing of overpasses and tunnels (UE8)
	Ease of transfer to public transport (UE9)
	Pavement design (UE10)
People's willingness to engage in physical activity (AW)	Satisfaction with the greenway (AW1)
	Willingness to go to the greenway for physical activity (AW2)

3.3. Modifications to the structural equation model and results

The modifications made to the structural equation model were mainly based on the MI (Modification Index) values and t values in the output results. In accordance with the principle of adjusting parameters in order of the associated MI value, from large to small, the observed variable corresponding to each of the relevant residual terms was removed or adjusted in turn under the premise of the model logic. In addition, under the premise that the model logic was reasonable, adjusted paths with a large MI value were added to analyze whether the adjustment was desirable by comparing the fit indices.

After the above adjustments to and modifications of the initial model, each model fit index was significantly improved compared with the original model; the model fit is shown in Table 8. After these modifications, the chi-square value for the model was 968.364, with 210 degrees of freedom, and the χ^2/DF ratio was 4.611, which is close to 3. Due to the large sample size of the questionnaire, the value was slightly higher, but still fell within acceptable limits. The RMSEA was close to 0.08, and the GFI, AGFI, CFI, IFI, and TLI were also close to 0.9. Again, due to the large sample size, the values deviated slightly, but they were all within the acceptable range. After modification, the overall fit of the model reached an acceptable standard, and a final structural equation model of the barriers to physical activity on the

TABLE 3 Studies on physical activity restrictions in greenways.

Variable	Categories	Number	Percentage
Sex	Man	164	50.9%
	Woman	158	49.1%
Age	<6 years old	0	0
	7–12 years old	0	0
	13–17 years old	6	1.9%
	18–30 years old	272	84.5%
	31–45 years old	18	5.6%
	46–60 years old	12	3.7%
	61–75 years old	10	3.1%
	>75 years old	4	1.2%
Household structure	Living alone	46	14.3%
	Family of two	24	7.5%
	Family of three	48	14.9%
	Family of 4–5	28	8.7%
	Other	176	54.7%
Education level	Junior high school or below	14	4.3%
	High school/vocational school	12	3.7%
	Undergraduate/junior college	194	60.2%
	Postgraduate or above	102	31.7%
Occupation	Public institution/civil servant/government work	8	2.5%
	Professional (e.g., teacher/doctor)	16	5.0%
	Service staff (e.g., driver/shop assistant)	2	0.6%
	Worker (e.g., factory worker/sanitation worker)	0	0

TABLE 4 KMO and Bartlett's tests.

KMO test		0.885
Bartlett's test of sphericity	Chi-square	8533.125
	DF	496
	Significance	0.000

community greenway among the population was determined, as shown in Figure 4.

3.4. Structural equation model path analysis

According to the results of the analysis of the revised measurement model and structural model, the overall goodness of fit of the model was high, and the model was assumed to be reasonable in this study. Therefore, the strengths of the influence between variables could be evaluated using standardized path coefficients, and the research hypotheses proposed above could be tested and analyzed. The results indicated that H2, H3, and H4 were valid: that is, user experience (UE), the greenway landscape (GL), and safety and accessibility (SA) each had a positive impact on people's willingness to engage in physical activity (AW), with path coefficients of 0.280, 0.205, and 0.163, respectively. However, H1 and H5 were not valid: that is, services and facilities (SF) and personal and interpersonal factors (PH) had no significant positive influence on willingness of the population to engage in physical activity (AW).

3.4.1. Analysis of the weights of influence among variables in the structural model

By analyzing the path coefficients listed in Table 9, it can be seen that in the case of Wenjiang Greenway, Chengdu, China, the ranking of potential variables restricting people's participation in physical activities in descending order of the weight of their influence was as follows: user experience (0.280) > the greenway landscape (0.205) > safety and accessibility (0.163). Therefore, on the whole, the "user experience" factor had the clearest restrictive

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TABLE 5 Summary of the results of EFA of restrictions to physical activity on the community greenway.

Underlying factors	Items	Cumulative variance explained	Factor loading coefficient
Safety and accessibility(SA)	Presence of sharp bulges in the seats and other facilities (SA1)	21.94%	0.821
	Absence of unsafe remote dead ends (SA2)		0.820
	Installation of guardrails in hazard zones (SA3)		0.811
	Motor vehicle parking (SA4)		0.804
	Blocking the condition of motor vehicle facilities (SA5)		0.801
	Surrounding traffic (SA6)		0.714
	Interference of pedestrians and bicycles with each other (SA7)		0.698
	Non-motor vehicle parking (SA8)		0.642
	Convenience of access (SA9)		0.578
User experience(UE)	Marker lines indicate the correct condition (UE1)	16.48%	0.802
	Prominent positioning of marker lines (UE2)		0.787
	Convenience of sideway crossing (UE3)		0.728
	Signs and lines are simple and easy to understand (UE4)		0.701
	Legibility of jogging lanes (UE5)		0.659
	Barrier-free design (UE6)		0.539
	Connectivity of the greenway to attractions (UE7)		0.509
	Ease of crossing of overpasses and tunnels(UE8)		0.506
	Ease of transfer to public transport (UE9)		0.435
	Pavement design(UE10)		0.409
Personal and interpersonal factors(PH)	My attitude toward fitness and sense of engagement (PH1)	11.53%	0.808
	Attitudes of friends and family toward fitness (PH2)		0.731
	My psychological health (PH3)		0.729
	My physical health (PH4)		0.723
	Time occupied by work/family (PH5)		0.650
	Have worked together (PH 6)		0.581
Services and facilities(SF)	Point-of-sale setup (SF1)	9.09%	0.748
	Provision of fitness and sports facilities (SF2)		0.690
	Installation and cleanliness of toilets and drinking fountains (SF3)		0.647
	Installation of streetlamps and other lighting (SF4)		0.574
Greenway landscape(GL)	Architectural style and shape of gardens (GL1)	6.61%	0.651
	Logo esthetics (GL2)		0.563
	Planting of garden plants and shading effects (GL3)		0.523

TABLE 6 Reliability of latent variables.

Factor	Cronbach's α	Number of items
Personal and interpersonal factors (PH)	0.847	6
Greenway landscape (GL)	0.814	3
Services and facilities (SF)	0.827	4
User experience (UE)	0.916	10
Safety and accessibility (SA)	0.944	9
People's willingness to engage in physical activity (AW)	0.925	2
Overall	0.953	34

TABLE 7 Analysis of initial model fit.

Goodness-of-fit measures	χ^2/DF	GFI	CFI	RMSEA
Before model modification	6.699	0.633	0.673	0.673
Recommended range	1–3	>0.9	>0.9	<0.08

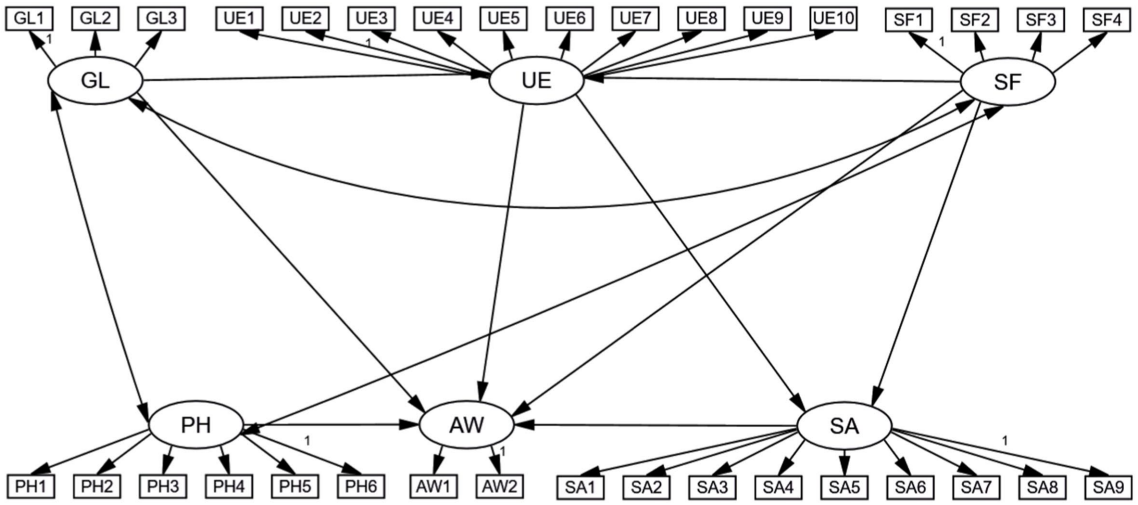

FIGURE 3
Initial model of factors restricting physical activity on the greenway among the population of the greenway community.

TABLE 8 Goodness of fit before and after model modification.

Goodness-of-fit measures	χ^2/DF	GFI	CFI	RMSEA
Before model modification	6.699	0.633	0.673	0.133
Modified model	4.611	0.809	0.853	0.106

effect on physical activity among the population, while the "safety and accessibility" factor had the least restrictive effect. The restrictive effects and influence of "services and facilities" and "personal and interpersonal factors" on physical activity among the population were inconsistent with the hypotheses. In addition, there was a positive correlation between the quality of "user experience" and "services and facilities" and the quality of "safety and accessibility," with the influence weights of 0.168 and 0.630, respectively, indicating that the influence of user experience on safety and accessibility was greater.

3.4.2. Analysis of the weights of influence among variables in the measurement model

The weights representing the influence of the relationship between each observed variable and the corresponding latent variable can be seen in the model path analysis diagram (Figure 5), as shown in Table 10. Among items relating to the greenway landscape, the weight of influence of each item, ranked in descending order, was: architectural style and shape of gardens (0.810) > logo aesthetics (0.785) > planting of garden plants and shading effects (0.725). In terms of the user experience factor, the ranking of the weight of influence of each item was: ease of crossing of overpasses and tunnels (0.774) > marker lines indicate the correct condition (0.763) > barrier-free design (0.760) > signs and lines are simple and easy to understand (0.702) > pavement design (0.693). Within the factor of services and facilities, the ranking of the weight of influence of each item was: installation of streetlamps and other lighting (0.814) > installation and cleanliness of toilets and drinking fountains (0.812) > point-of-sale setup (0.771). Among the items relating to safety and accessibility, the ranking of the weight of influence of each item was: presence of sharp bulges in the seats and other facilities (0.904) > absence of unsafe remote dead ends (0.885) > installation of guardrails in hazard zones (0.878) > blocking the condition of motor vehicle facilities (0.783) > non-motor vehicle parking (0.724) > interference of pedestrians and bicycles with each other (0.677). Among the items falling under personal and interpersonal factors, the raking of the weight of influence of each item was: my physical health (0.822) > my recent physical condition (0.773) > attitudes of friends and family toward fitness (0.759) > my attitude toward fitness and sense of engagement (0.595). Finally, among items relating to people's willingness to engage in physical activity, the weight of influence of overall satisfaction with the greenway (0.946) was greater than that of their willingness to go to the greenway for physical activity (0.911).

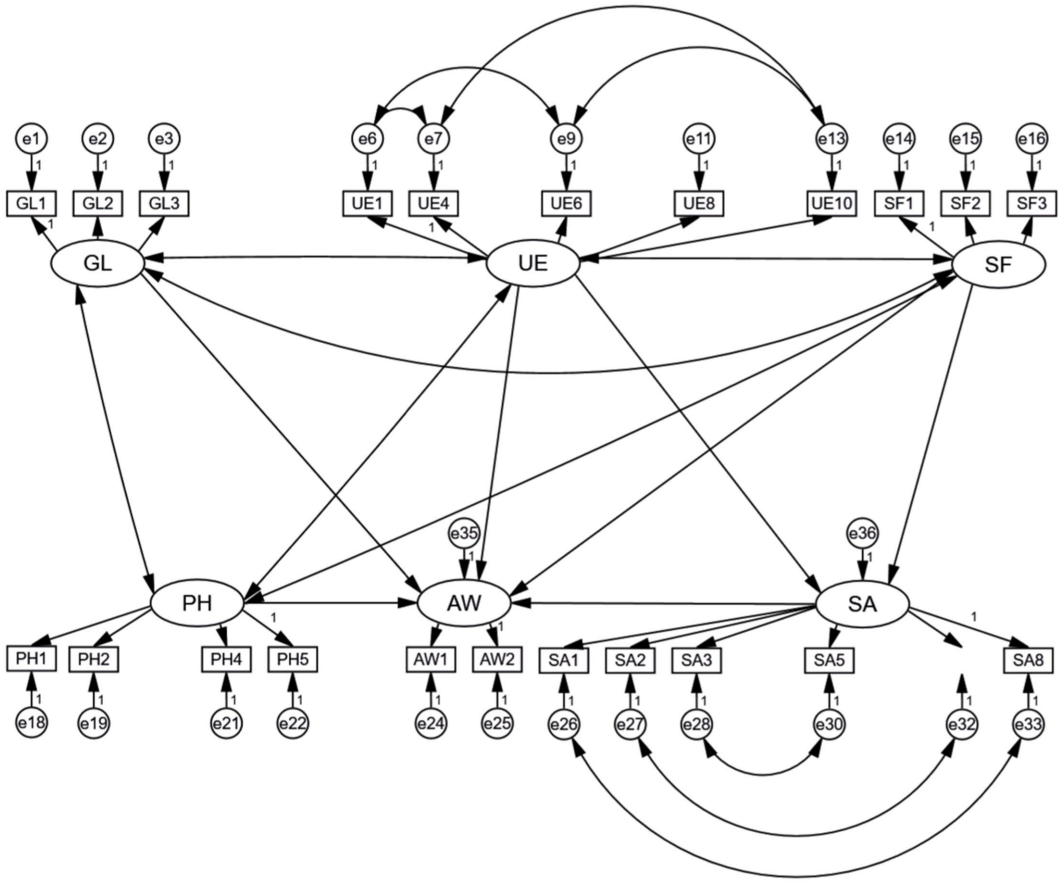

FIGURE 4
Structural equation model of factors restricting physical activity on Wenjiang Nancheng Greenway.

TABLE 9 Path coefficients in the structural equation model.

Path between variables	Path coefficient
Safety and accessibility<—-- Services and facilities	0.168
Safety and accessibility<—--User experience	0.630
People's willingness to engage in physical activity<—--Greenway landscape	0.205
People's willingness to engage in physical activity<—--User experience	0.280
People's willingness to engage in physical activity<—--Services and facilities	−0.263
People's willingness to engage in physical activity<—--Personal and interpersonal factors	−0.190
People's willingness to engage in physical activity<—--Safety and accessibility	0.163

4. Discussion

4.1. Objective constraints on the willingness of people to engage in physical activity on community greenways

In terms of objective environmental characteristics, previous studies have mostly explored the correlation between the environmental characteristics of public green spaces and their use for leisure activities from the perspective of promoting people's engagement in leisure activities; in contrast, this study focused on the influencing factors and mechanisms that act as restrictions preventing people from using community greenways to engage in more physical activities. In this study, safety and accessibility were found to be important factors and mechanisms restricting people's use of community greenways for physical activity. In terms of accessibility, the more distant and less accessible a community greenway is from where residents live, the lower the willingness of people to travel to the greenway for physical activity; reasonable organization of the flow of traffic and the availability of suitable parking spaces for private vehicles also affect residents' willingness to travel. For instance, Lawrence et al. investigated the effect of urban greenway renovation on people's engagement in physical activity and sedentary behavior, and concluded that accessibility is an important factor in enhancing people's willingness to engage in physical activity (51); some scholars have also shown that as distance increases, the frequency of green

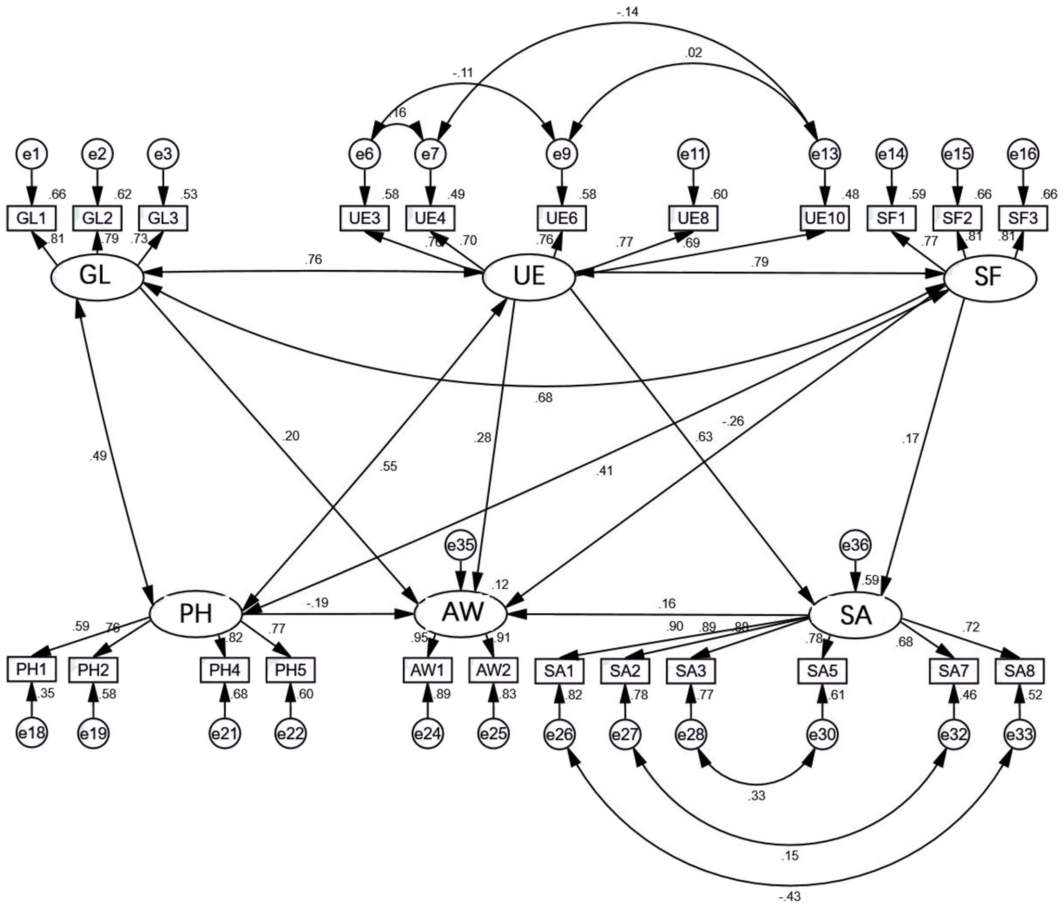

FIGURE 5
Path analysis in the model.

space use decreases, leading to a decrease in the probability of residents' using green space for physical activity and their willingness to do so (52–54). In terms of safety, existing studies have focused on the differences between different types of environments in terms of the perceived safety of users (55) and the correlation between the configuration of visual elements and users' perceived safety (56), while some scholars have confirmed through empirical studies that safety can have a significant impact on people's willingness to engage in physical activity and on the benefits of physical activity (57, 58). In this study, it was found that the presence of hidden safety risks at recreational sports facilities, a low sense of security created by activity spaces, and imperfect safety measures in dangerous areas are important barriers to use of community greenways for physical activities. This study also revealed the aspects of the greenway landscape that act as restrictions to people's use of community greenways for physical activities and the mechanisms by which these restrictions act. A single type of greenway landscape and poor quality of the landscape environment are important factors that restrict people's access to greenways for physical activity. Zhang and colleagues explored the influence of the greenway landscape environment on users' leisure activities through machine vision, but their study found that the environmental characteristics of the greenway do not affect the distribution of leisure activities engaged in (59). In addition, this study found that when the greenway landscape does not reflect the esthetic philosophy and values of the users, this will greatly constrain users' willingness to engage in physical activity. The findings of this study are similar to those of previous studies: for example, Junga et al. demonstrated that greenway landscape features are positively associated with users' perceived and preferred experiences, thereby influencing users' willingness to engage in physical activity (60). Similarly, Bao et al. showed that satisfying the demand for physical activity in neighborhood spaces through the proper configuration of neighborhood spatial and environmental features is conducive to enhancing people's willingness to engage in physical activity (61). According to the results of this study, services and facilities do not have a constraining effect on people's willingness to engage in physical activity in community greenways: i.e., the installation and distribution of services and facilities in community greenways does not restrict people's willingness to engage in physical activity in these spaces. This contradicts previous studies, which have shown that both greening rates and the number of neighborhood fitness facilities can promote residents' engagement in recreational physical activity and willingness to engage in physical activity (62). For example, Zhai et al. explored the effect of the configuration of park facilities on the intensity of physical activity among older adults, and the study confirmed a significant correlation between the intensity of physical activity and the type and quality of the configuration of park facilities (63). Additionally, Jenny et al. demonstrated that the upgrading of park services helps to increase visitors' willingness to engage in physical activity and the vitality of the spatial environment (62).

TABLE 10 Path coefficients in the measurement model.

Latent variable	Observed variable	Path coefficient
Greenway landscape (GL)	Architectural style and shape of gardens (GL1)	0.810
	Logo esthetics (GL2)	0.785
	Planting of garden plants and shading effect (GL3)	0.725
User experience (UE)	Marker lines indicate the correct condition (UE1)	0.763
	Signs and lines are simple and easy to understand (UE4)	0.702
	Barrier-free design (UE6)	0.760
	Ease of crossing of overpasses and tunnels (UE8)	0.774
	Pavement design (UE10)	0.693
Services and facilities (SF)	Point-of-sale setup (SF1)	0.771
	Installation and cleanliness of toilets and drinking fountains (SF3)	0.812
	Installation of streetlamps and other lighting (SF4)	0.814
Safety and accessibility (SA)	Presence of sharp bulges in the seats and other facilities (SA1)	0.904
	Absence of unsafe remote dead ends (SA2)	0.885
	Installation of guardrails in hazard zones (SA3)	0.878
	Blocking the condition of motor vehicle facilities (SA5)	0.783
	Interference of pedestrians and bicycles with each other (SA7)	0.677
	Non-motor vehicle parking (SA8)	0.724
Personal and interpersonal factors (PH)	My attitude toward fitness and sense of engagement (PH1)	0.595
	Attitudes of friends and family toward fitness (PH2)	0.759
	My physical health (PH4)	0.822
	Time occupied by work/family (PH5)	0.773
People's willingness to engage in physical activity (AW)	Satisfaction with the greenway (AW1)	0.946
	Willingness to go to the greenway for physical activity (AW2)	0.911

4.2. Subjective constraints on the willingness of people to engage in physical activity on community greenways

In terms of subjective personal factors, previous studies have mostly started from the personal characteristics of users to explore the relationship between their personal attributes, such as gender, age, and occupation (64), and the use of green public spaces; in contrast, this study explored the mechanisms underlying factors hindering users' willingness to engage in physical activity from the perspective of users' physiological, psychological, and interpersonal characteristics. This study found that there was no inhibitory relationship between the personal and interpersonal characteristics of users and people's intentions to engage in physical activity on community greenways, indicating that users' individual characteristics and interpersonal relationships did not act as restrictions preventing them from going to the greenway for physical activity. This is not in line with the results of existing studies: in terms of the individual characteristics of residents, it has been demonstrated that older adults are more likely to exercise on greenways than younger people, and that greenways have important health benefits for middle-aged and older adults who are exposed to health risks. In addition, residents with higher levels of education, higher annual income, and good health status use greenways more frequently and report higher willingness to engage in physical activity, so these characteristics are likely to promote the improvement of physical activity levels through the use of greenways (65). In terms of peer relationships, Zhu et al., in considering the moderating effects of social support in the relationship between neighborhood green spaces and residents' engagement in physical activity as a form of leisure, found that an increase in the number of exercise-loving friends among residents would only enhance the positive effect of greening rate, but in turn would weaken the positive effect of increasing the availability of fitness facilities on the degree of engagement in physical activity for leisure (66). This study also revealed that personal experience of greenway use is an important factor that hinders users' willingness to engage in physical activity. Improving user experience and satisfaction with public space can enhance users' willingness to engage in physical activity (67). Zhao et al. demonstrated that the subjective perception of humanized space has a direct impact on the duration of physical activity among the public, while the connectivity of the destination and the degree to which the landscape is maintained have an indirect impact on the level of physical activity among the public via the subjective perceptions and user experience of users (68).

5. Conclusion

With a focus on restrictions, this study explored the factors influencing people's willingness to engage in physical activity on community greenways, indicating that community greenways can provide support for community residents in the form of a space for them to carry out healthy physical activity and daily leisure activities;

however, there are also many factors restricting such participation. Adopting a field investigation methodology along with theoretical modeling of hypotheses regarding the factors restricting people's use of community greenways for physical activity, an empirical study was conducted, taking Chengdu community greenways as the object of research to explore the correlations of the landscape, the safety and accessibility of greenways, and the user experience with people's intentions to engage in physical activity. The results of the analysis of the effects of services and facilities, and of individual and interpersonal factors, showed that although the data observed were inconsistent with the hypotheses, these factors still have certain constraining effects on people's willingness to engage in physical activity.

This study has several limitations. First, the empirical investigation reported in this article was conducted in the early winter season. Due to the specific limitations of the season, the number and type of interviewees was insufficient, and the collected data (and thus the results of the analysis) were not sufficiently representative enough of users during other seasons. In addition, all questionnaires were designed with the support of a large body of literature, including expert interviews and pre-research. However, the ways in which certain items were expressed in the final questionnaire may have been slightly obscure to some non-professionals, resulting in incomplete understanding of the full intention of some items of the questionnaire.

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 authors.

Author contributions

EF provided the research ideas and formulated the overall research objectives, reviewed the literature in the early stage of the experiment, participated in the research and investigation process during the research process, guided and participated in the article writing process. XD conducted the field survey, participated in the analysis of the questionnaire and the data, and was responsible for writing the results, discussion and summary of the paper. YW prepared the preliminary questionnaire, and participated in the field survey and the distribution, sorting and analysis of the questionnaire. LL participated in the field investigation of this study and the writing and translation of the article. YX participated in the field investigation and writing and translation of the study. ML participated in the writing and translation of the article. ZZ participated in the writing and translation of the article. JD guided the writing of this paper and provided help with the research methods and ideas. XnL participated in the writing and translation of the study, and participated in the experimental preparation process of the study. XiL provided theoretical guidance for this study and provided funding.

Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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.2023.1169728/full#supplementary-material

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Exploring perceived restoration, landscape perception, and place attachment in historical districts: insights from diverse visitors

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Improving the quality of the built environment to enhance people's mental health is gaining traction across various fields, precipitating valuable actions on the wave of "Healthy China 2030" initiative. While ample studies have confirmed the benefits of interaction with natural or green spaces, the investigation into the restorative potential in urban built settings remains notably underexplored. In this study, we focused on historical districts, conducting a questionnaire survey to evaluate the restorative experiences of individuals visiting these sites. We used Partial Least Square-Structural Equation Modelling (PLS-SEM) to analyze a conceptual model that encompasses landscape perception, place attachment, and perceived restoration, with a specific focus on detecting the mediating role of place attachment and the moderating influence of visitor groups. The results showed that landscape perception significantly influenced the perceived restoration, which contained the indirect effect pathway through place dependence and place identity, as well as the potent direct impact of landscape perception. Moreover, employing a multi-group analysis (MGA), we discerned that different visitor groups partially moderate the relationship between landscape perception, place attachment, and perceived restoration. This study validates the restorative features in historic districts and highlights the importance of cognitive-emotional bond in promoting psychological restoration.

KEYWORDS

perceived restoration, place attachment, historical district, structural equation model, landscape perception, visitor groups

1. Introduction

The process of rapid urbanization has resulted in multifaceted challenges to urban planning and designing, particularly in creating livable environments conductive to human health (Haaland and van den Bosch, 2015). These challenges, which include overpopulation, social isolation, traffic-induced air pollution, and the urban heat island effect, have adversely affected the well-belling of urban residents, leading to both physical and mental illnesses (Haaland and van den Bosch, 2015; Feltynowski et al., 2018). Despite a growing body of evidence demonstrates the positive association between urban green spaces and human mental health, the availability of these crucial spaces is progressively diminishing due to high-density urban development (Hartig et al., 2003; Nordh et al., 2009; Grahn and Stigsdotter, 2010). Consequently, the opportunities for engaging in green recreational activities are becoming increasingly limited (Haaland and van den Bosch, 2015; Lin et al., 2015). Therefore, there is a growing awareness of

the need to find alternative open spaces and develop infrastructure in urban built environments that prioritize health promotion (Stigsdotter et al., 2017; Subiza-Pérez et al., 2021). This imperative requires immediate attention rather than deferral to the future.

Perceived restoration refers to the progress of improving emotional, physical and attentional states by relieving cognitive fatigue and emotional disorder (Kaplan, 1993; Kaplan, 1995). Although empirical studies suggest a much stronger stress-reductive capacity of natural environments compared to urban settings (Kaplan, 1995; Grahn and Stigsdotter, 2010; Van den Berg et al., 2010), it is important to note that the restorative experience is not solely connected with natural elements (Weber and Trojan, 2018). Indeed, positive emotional support can occur in various types of environments, as long as these settings would meet the requirements of a restorative environment (Kaplan, 1995; Scopelliti et al., 2019). Evidence is emerging that a well-designed urban setting also has a beneficial effect similar to that of nature (Kaplan et al., 1993; Gascon et al., 2017; Xu et al., 2018). For example, the monastery could provide an opportunity to experience mental restoration from a spiritual release perspective (Ouellette et al., 2005). The local history square may offer pleasure and relaxation comparable to that found in urban parks (Fornara and Troffa, 2009). As a place of healing, cultural heritage sites could improve tourist satisfaction and restorative experiences (Cho et al., 2016), with the integration of more water features and flat terrains significantly contributing to the restoration of such cultural landscapes (Xu et al., 2018). Historical districts, combining traditional features, cultural characteristics, and local traits, deeply rooted in the urban memory of the locality (Naoi et al., 2011). As essential components of cultural heritage, these districts not only witness urban development and culture evolution, but also play a vital role in the promotion of urban renewal, enhancement of public environments, and refinement of supporting facilities (Lu et al., 2015; Wang and Aoki, 2019). However, to our knowledge, there is still a lack of empirical research on this type of place to reveal the possibility of the perceived restoration effect.

In addition, a large body of research highlights the materiality of both tangible and intangible factors that may influence restorative experiences (Herzog et al., 2003; Nordh et al., 2009; Grahn and Stigsdotter, 2010; Dallimer et al., 2012). On the one hand, the impact of environmental perception and preference in facilitating individual perceived restoration has been extensively recognized (Herzog et al., 2003; Nordh et al., 2009; Grahn and Stigsdotter, 2010). Dallimer et al. (2012), for example, proposed that the psychological restoration experienced by visitors correlates more with their perceived species diversity rather than the actual species diversity within urban green spaces. Similarly, Subiza-Pérez et al. (2019) indicated that esthetic enjoyment serves as a significant motivation for visiting urban green and blue spaces, with crucial implications for perceived restoration and engagement in physical activities. Masullo et al. (2021a) reported that adding water installations with combined auditory and visual elements can greatly enhance individual restorativeness in environments with background traffic noise. On the other hand, the emotional connections fostered through human-land interactions also play an essential predictive role in restorative environments (Menatti et al., 2019; Subiza-Pérez et al., 2020). The stronger the place attachment to a given place, the more profound the experience of restorative outcomes (Menatti et al., 2019). The psychological enjoyment derived from a place is directly associated with the recovery experience (Korpela et al., 2001). Arguably, perceived restoration is an intricate combination of environmental perception, human cognition, and mental emotion (Scopelliti and Vittoria, 2004).

Moreover, emotional attachment belongs to the dynamic response variable for visitors, exhibiting potential subject disparities (Lewicka, 2010). For example, place attachment tends to be more intensely experienced by visitors who live in close proximity than by those from more distant locations (Kil et al., 2015), and it is also positively related to the length of residence (Brown and Raymond, 2007). Historical districts offer more than just opportunities for tourists to immerse themselves in local history and cultural activities. They also serve as indispensable venues for outdoor recreation for local residents (Wang and Aoki, 2019). Given the potential differences in place attachment between residents and tourists, it is necessary to analyze whether these disparities affect their restorative experiences in historic districts.

With the proposal of "Healthy China 2030" strategic initiative, improving public health has become an essential concern within Chinese society (Tan et al., 2017). Mental health, representing an indispensable dimension of overall well-being, is a breakthrough for ensuring the public have access to healthy life. Considering the above issues, this study aims to systematically understand the supportive qualities that contribute to restorative experiences within the context of historical districts. First, we examined the influence paths between landscape perception, place attachment, and perceived restoration. Second, we detected whether the place attachment could play a mediating role between landscape perception and perceived restoration. Third, we investigated the moderating impact of different visitor groups for the overall conceptual model. We believe the findings could provide an insight into the debate regarding restorative urban built environment, while also providing references for the preservation management and renewal development in historical districts.

2. Literature review and conceptual framework

2.1. Landscape perception and perceived restoration

According to the Attention Recovery Theory (ART), engaging in many activities that require effortful attention and lead to mental fatigue when individuals' capacity becomes depleted due to excessive use (Kaplan, 1995). ART identifies four key features of a restorative environment that improve psychological restoration and stress alleviation (Kaplan and Kaplan, 1989; Hartig et al., 1997): 'being away' (flighting from daily routine life and exhausted things), 'fascination' (engaging attention through specific environmental objects and features), 'compatibility' (alignment between personal intentions and environmental activities) and 'extent' (immersing oneself into a context distinct from the current one, including both tangible and intangible elements). The environment with 'extent' does not necessarily require a large area of space but should be coherent and have a sense of depth. Therefore, the 'extent' can be measured by the property of 'coherence' and 'scope' (Hartig et al., 1997; Pasini et al., 2014; Celikors and Wells, 2022). The 'coherence' means an individual's perception of harmony within the environment, while 'scope' refers to the scale of the environment and what can be achieved there (Hartig et al., 2003; Pasini et al., 2014).

Landscape perception refers to the process by which the human brain acquires environmental information through the sensory system, subsequently followed by emotional processing of these information (Purcell, 1987; Mesch and Manor, 1998; Kyle et al., 2004). In other words, landscape perception relies on subjective feelings and psychological evaluations of environment surroundings, also addicted to the psychological basis of people's environmental behavior (Purcell, 1987; Tschacher et al., 2012). Several studies have explored the indicators and dimensions of landscape perception that can be measured and evaluated across various urban settings (Palacio Buendía et al., 2021). For example, Gobster and Westphal (2004) investigated the human recreation experiences in the urban greenway, utilizing cleanliness, naturalness, esthetics, safety, and access as evaluative indicators. Sotoudeh and Abdullah (2013) summarized six cognitive properties associated with historical buildings, they are coherence, friendly, novelty, complexity, meaningful, and pleasant. In historical districts, visitor evaluations are significantly influenced by key perception features such as touristic, safety, calm, lively, unique, and famous (Naoi et al., 2006). Besides, the unique architectural facades have a positive impact on visitors' psychological impression. The building styles and their cultural atmosphere can trigger 'romantic' emotions and states of mind in visitors (de Freitas et al., 2021).

Regarding the link between landscape perception and perceived restoration, subjective landscape perception has been widely identified as significantly correlated with psychological restoration (Ojala et al., 2019; Malekinezhad et al., 2020). For example, Grahn and Stigsdotter (2010) proposed eight perceived sensory dimensions in urban parks as most pertinent to stress relief, including culture, nature, prospect, refuge, rich in species, social, space and serene. Mahdieh et al. (2011) found that visual perception preferences for urban natural landscapes greatly enhanced their restorative experience. In addition, in urban environments with historical and cultural characteristics, landscape perception is also closely related to the restorativeness (Hidalgo et al., 2006; Fornara and Troffa, 2009). The work of Hidalgo et al. (2006) informed that esthetic preference for history places contributes to the creation of a mental recovery experience. Fornara and Troffa (2009) confirmed that historic sites and urban parks have similar restorative qualities and characteristics. Masullo et al. (2021b) indicated that historical–artistic features present in historical sites are closely related to all the components of restorativeness, particularly the component of fascination. Liu et al. (2019) indicated that a positive soundscape perception in historic blocks could contribute to visitor satisfaction during the visiting experience. In light of these findings, it is inferred that landscape perception could enhance restorative experiences by processing environmental features-related information. Moreover, historical districts, with their unique esthetic characteristics and emotional attributes, also could support perceived restoration for visitors. The following hypothesis thus was proposed:

> *H1*: Landscape perception has a significant positive effect on perceived restoration.

2.2. Landscape perception and place attachment

Place attachment refers to the connection individuals establish with their environment, encompassing the interaction of emotion, perception, and behavior (Williams and Vaske, 2003). It not only carries conceptual significance in explaining the intrinsic connection between individuals and specific places but also has application value in rebuilding positive emotional bonds (Raymond et al., 2010; Ujang and Zakariya, 2015). The classical two-dimensional structure of place attachment (i.e., place dependency and place identity) has been proven reliable and universal in environmental psychology research (Williams and Vaske, 2003; Jorgensen and Stedman, 2006; Liu et al., 2020). Place dependence emphasizes the physical attachment and functional dependence on facilities or settings, reflecting the specific conditions in which the environment supports the individual's activities (Jorgensen and Stedman, 2006; Brown and Raymond, 2007). Place identity is part of personal identity, which depends on the typical elements of a specific area and the special sense of belonging (Wester-Herber, 2004; Hernández et al., 2007). Notably, factors such as place-related memories, social interactions, and leisure activities are associated with the formation of place attachment (Ratcliffe and Korpela, 2016; Hosseini et al., 2021). Besides, place attachment also influences behavioral intentions, neighborhood belonging, and psychological recovery (Kyle G. T. et al., 2003).

In addition, studies on cognitive perception and human-land interaction started to increase in past decades (Mesch and Manor, 1998; Bratman et al., 2012; Hosseini et al., 2021). Mesch and Manor (1998) found that a high evaluation of physical and social environment usually represents a greater potential for place attachment. Stedman (2002) argued that place attachment relies on the understanding of the environment and can be fostered only when 'the feeling' occurs in the place. Bratman et al. (2012) indicated that the psychological benefits of nature experiences were presumed to be the result of a cognitive process in the specific environment. In other words, place attachment is a part of the self-psychological framework, where cognition and emotion connect individuals to their environment (Fiske et al., 2007). In terms of historical landscape, understanding perception and satisfaction of visitors is a foundation for better protecting and managing cultural heritage sites (de Freitas et al., 2021). Based on the above evidence, this study assumed that the landscape perceptions could induce different levels of human-land emotional responses in historical districts. Hence, we formulated the following hypotheses:

> *H2*: Landscape perception has a significant positive effect on place attachment.
>
> *H2a*: Landscape perception has a significant positive effect on place dependence.
>
> *H2b*: Landscape perception has a significant positive effect on place identity.

2.3. Place attachment and perceived restoration

The relationship between place attachment and perceived restoration has been confirmed in recent studies (Menatti et al., 2019; Kastenholz et al., 2020). People find it easier to spend time and obtain relaxing experiences in places with high attachment levels (Kyle G. et al., 2003; Lewicka, 2008; Ratcliffe and Korpela, 2016). Thus, fostering stronger place attachment bonds among visitors could

positively impact psychological states (Pretty et al., 2016). Korpela et al. (2001) reported that the enjoyment of a place is directly proportional to the recovery experience. Ratcliffe and Korpela (2016) found that the memory properties displayed a predictive effect on perceived restoration, with place attachment as a mediating variable. Additionally, regarding the sub-dimensions of place attachment, both place identity and place dependence were consistently associated with perceived restoration (Ratcliffe and Korpela, 2016). Liu et al. (2021) suggested that place identity is a more potent predictor of restorativeness in urban parks compared to place dependence. These outcomes make it evident that restorative experiences are related to the individual's affective attitudes; thus, the following hypotheses were tested:

> *H3*: Place attachment has a significant positive effect on perceived restoration.
>
> *H3a*: Place dependence has a significant positive effect on perceived restoration.
>
> *H3b*: Place identity has a significant positive effect on perceived restoration.

2.4. Place dependence and place identity

It is also important that place dependence and place identity were initially often studied side by side. However, as research progressed, scholars became aware of the potential recursive relations between identity and dependence (Stedman, 2002; Hernández et al., 2007; Liu et al., 2020). Halpenny (2010) found that the impact of place dependence on visitors' pro-environmental intentions is mediated by place identity. Similarly, Wan et al. (2022) proposed that place dependence indirectly influences recycling intention through place identity. That is to say, people are more likely to develop a sense of emotional identification and belonging (i.e., place identity) if one place can provide the physical conditions and characteristics to meet individual needs (i.e., place dependency) (Trąbka, 2019; Wan et al., 2022). Based on the above outcomes, there is also a possibility of precedence from place dependence to place identity in visiting historical districts. Thus, we proposed following hypothesis:

> *H4*: Place dependence has a significant positive effect on place identity.

2.5. The moderating effect of visitor groups

Regarding the participants, status on environment perception and emotional connection, several studies have confirmed the different perspectives between residents and visitors (Home and Vieli, 2020; Dasgupta et al., 2022; Guo et al., 2022). For example, Vaz de Freitas et al. (2021) discovered that residents value heritage conservation and transport mobility more in urban landscape, while visitors place more importance on pedestrian mobility and esthetic quality. Giannakopoulou et al. (2011) employed contingent valuation surveys to assess the perceptions and attitudes of local residents and visitors toward the preservation of traditional architecture. The findings revealed that residents exhibited greater awareness of the actual extent of architectural decay and demonstrated a higher level of concern for its protection. As historical and cultural districts play a crucial role in leisure living spaces for residents and visiting places for tourists, the status of different visitors may have a moderating role in the influencing mechanisms of landscape perception, place attachment, and perceived restoration. Thus, we proposed the following hypotheses:

> *H5*: Visitor groups have a significant moderating effect on the relationships between landscape perception and perceived restoration (H5a); landscape perception and place dependence (H5b); landscape perception and place identity (H5c); place dependence and perceived restoration (H5d); place identity and perceived restoration (H5e); place dependence and place identity (H5f).

In summary, the aim of this study is to systematically investigate the restorative qualities of historical districts that influence the perceived restoration experienced by diverse visitor groups. The research developed a conceptual model to analyze the connections between landscape perception, place attachment, and perceived restoration; meanwhile, a PLS-SEM was employed to detect these relationships (Figure 1).

3. Methodology

3.1. Study area

Tianjin, located in northern China, is an early city with historic connections to Western civilization. Since it was established as an important commercial port in 1860, the city has built and reserved many exotic-style buildings along Haihe river. Over time, these buildings and their surroundings gradually merged with the city's development plans, culminating in unique historical and cultural districts. These districts now stand as prominent landmarks in Tianjin, representing the city's distinctive heritage and symbol. In this study, two typical historical districts were selected as sample sites. One is the Five

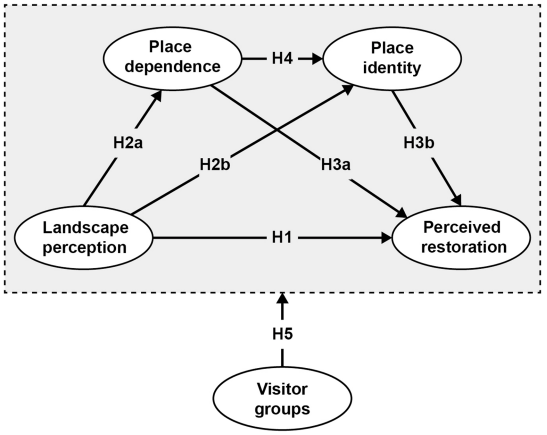

FIGURE 1
Conceptual framework.

Avenues Historical and Cultural District, and another is the Yigong Garden Historical and Cultural District (Figure 2). The selection criteria for these sites were as follows. First, the two sites serve as dual roles for tourism and leisure, meeting the requirements of both daily recreation and cultural experiences. Second, these locations maintain distinctive architectural features and well-preserved streetscapes, drawing a large number of visitors for sightseeing and touring.

3.2. Questionnaire design

Based on previous studies (Pazhouhanfar and M.s. MK., 2014; Home and Vieli, 2020; Liu et al., 2020; Malekinezhad et al., 2020), we formulated a questionnaire, including four sections and 30 statements. The questionnaire was translated from English into Chinese and subsequently pre-tested by employing twenty college students to ensure its acceptability and accuracy. The four parts are as follows:

Demographic characteristics: The factors in this part contained gender (male and female), age (<18, 18–40, 41–65, >66), education (below high school, high school, undergraduate, and above undergraduate), occupation (student, employed, unemployed, and retired), and visitor status (long-time residents, short-time residents, and transient tourists). Long-term residents in Tianjin are defined as individuals who have lived in the city for a minimum period of six months and fulfill one of the following requirements: legal employment, stable residence, or continuous education. Short-time residents encompass individuals who have temporarily settled in Tianjin for at least one month and are engaged in work or business activities. Lastly, transient tourists pertain to individuals who visit Tianjin for a short period solely for tourism purposes.

Perceived Restorativeness Scale: Considering the integrity and efficiency of the evaluation, this study used a concise version of the Perceived Restorativeness Scale (PRS-11) as proposed by Pasini et al. (2014). The PRS-11 scale is condensed to collect data in a shorter time and regardless of gender or nationality, which has been widely applied in the evaluation of various restorative environments, such as urban garden (Home and Vieli, 2020), cemetery (Nordh et al., 2017), and campus (Shrestha et al., 2021). This scale includes eleven statements in four dimensions: 'Fascination', 'Coherence', 'Scope', and 'Being away'. Likert seven-point scales were used for this scale.

Place Attachment Scale: Given that the classical two-dimensional structure of place dependence and place identity is widely applied, we employed an eight-item scale across two dimensions, following their successful utilization in previous studies (Williams and Vaske, 2003; Lewicka, 2008; Hosseini et al., 2021). Specifically, four items were designed to measure place dependence and four items to measure place identity, with some minor adjustments to better fit the context of the historical district (Williams and Vaske, 2003; Kyle et al., 2005). Likert seven-point scales were used for this scale.

Landscape Perception Evaluation: This section addressed the subjective evaluation of landscape perception in historical districts, using widely validated indicators from previous studies (Gobster and Westphal, 2004; Grahn and Stigsdotter, 2010; Tempesta, 2010; Liu et al., 2019). We focused on six dimensions of perception evaluation, which include 'esthetic', 'historical', 'unique' 'pleasant', 'natural', and

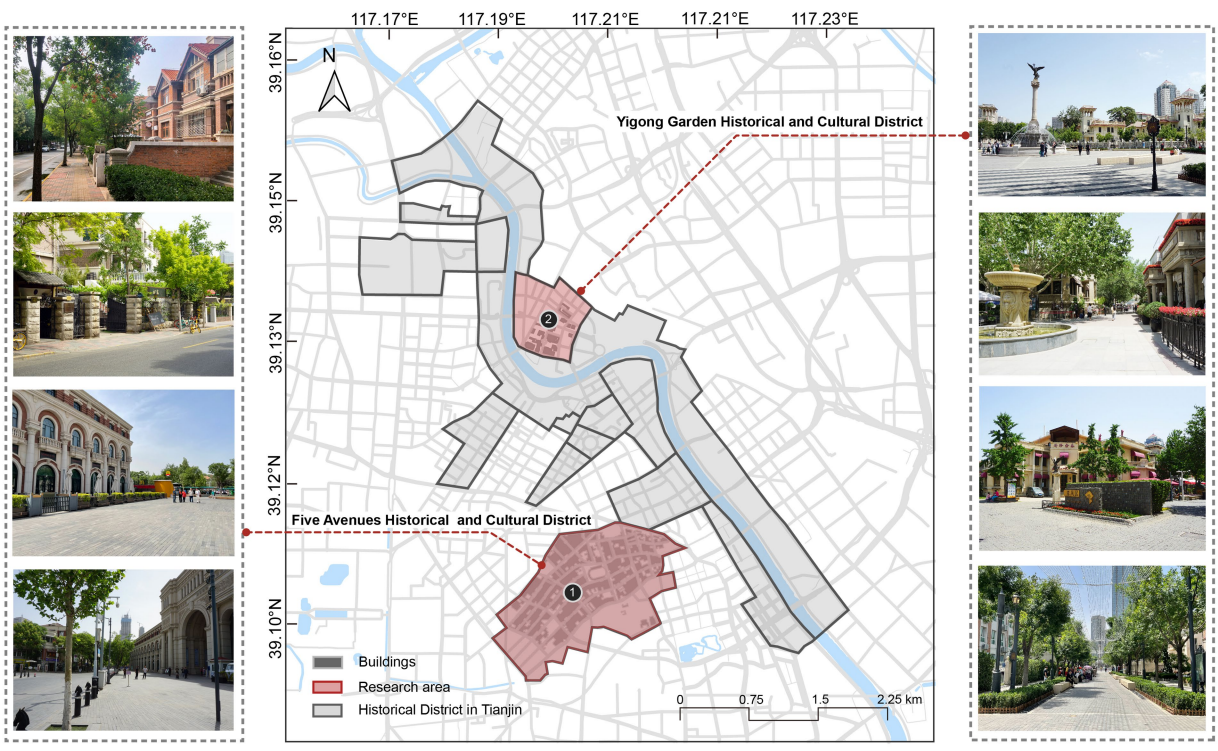

FIGURE 2
Study area and field photographs of the two selected historical districts (Base map: Reproduced with permission from https://map.baidu.com. City photos: Taken by the authors).

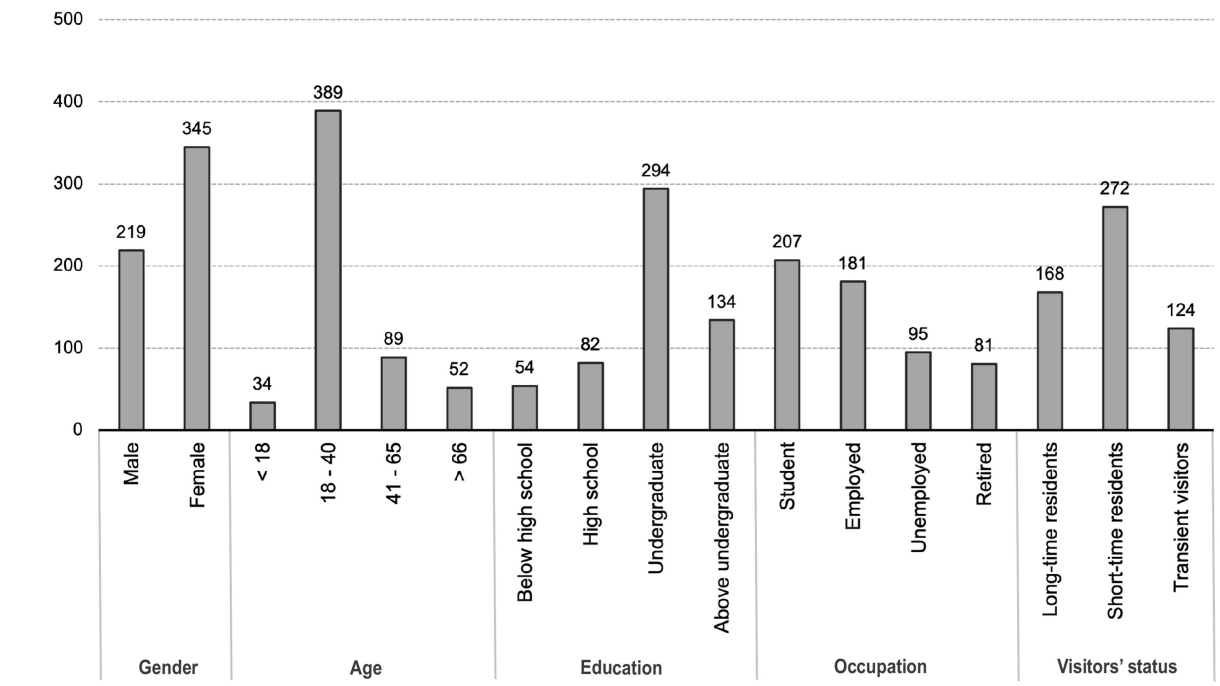

FIGURE 3
Demographic characteristics of the participants in this questionnaire.

'safety'. Each item was measured with seven-point semantic differential scales using the evaluative adjective.

3.3. Data collection and analysis

Data were collected from November 2020 to May 2021 on days with good weather conditions. The participant was randomly selected from visitors who had actually visited the historical districts to ensure the collected data accurately represented authentic visiting experiences. All participants were informed by the interviewers about the purpose of the study, the research methodology, the affiliations of the institution, and why their participation was essential. They were further assured of the anonymity of their responses and the confidentiality of the information they provided. Before participating in the study and filling out the questionnaire, participants confirmed they understood the instructions and consented to their involvement in the research.

A total of 620 questionnaires were given out, and 564 responses were returned, representing a 90.96% response rate. The data was processed in SmartPLS 4.0, and we organized follow steps for the statistical analysis. Firstly, we tested the validity and reliability of each item. Secondly, we used PLS-SEM to detect the relationships between landscape perception, place attachment, and perceived restoration. PLS-SEM is a comprehensive approach that can examine complex models with direct and indirect relationships, which is suitable for the research of main concerns are theory development and prediction (Hair et al., 2019). Thirdly, we analyzed the mediating role of place attachment in the generation mechanism of perceived restoration. Finally, the Multiple Group Analysis (MGA) was applied to examine the difference between the three visitor groups.

4. Results

4.1. Descriptive statistics characteristics

The demographic characteristics of the participants in this questionnaire are shown in Figure 3. The participant consisted of 61.2% females and 38.8% males. Regarding age, 69.0% of participants in the sample were 18 to 40 years old, 6.1% were below 18 years old, and 24.9% were aged 41 years old and above. Regarding education attainment, participants with undergraduate degrees (52.1%) and above undergraduate education backgrounds (23.7%) occupied a large proportion. For occupation differences, participants of the student, employed, unemployed and retired accounted for 36.7, 32.0, 16.8, and 14.5%. In terms of visitors' status, the majority of participants were short-time residents (48.2%), followed by long-time residents (29.8%), and transient tourists (22.0%).

4.2. Reliability and validity

Table 1 presents the reliability and validity for each item. Firstly, Cronbach's alpha coefficient (α) was applied to test the reliability of the questionnaire. The results indicated good internal reliability and stability, with the α values ranged from 0.813 to 0.892, all exceeding the recommended threshold of 0.8 (Shevlin et al., 2000). Secondly, the validity of the questionnaire was examined using average variance extracted (AVE) and combined reliability (CR), with 0.5 and 0.7 as the reference threshold, respectively (Hair et al., 2010). The analysis showed that AVE values ranged from 0.589 to 0.842, while CR ranged from 0.889 to 0.931. These results indicate good convergent validity

TABLE 1 Construct reliability and validity analysis.

Variable	Item	Standard deviation	Cronbach's α	AVE	CR
	Place attachment				
Place dependence	Pd1 When I want to do outdoor recreation, this is the best place I go to.	0.848	0.845	0.683	0.895
	Pd2 This place is more worth visiting than other places.	0.701			
	Pd3 The leisure activity experience here is more satisfying than anywhere else I have been.	0.884			
	Pd4 No other place can compare to this place.	0.860			
Place identity	Pi1 I have a lot of personal memories link in here.	0.886	0.892	0.756	0.925
	Pi2 I feel this place is an integral part of my life.	0.880			
	Pi3 I identity strongly with visiting in here.	0.843			
	Pi4 I am very attached to this place.	0.868			
	Perceived restoration				
Being away	B1 This district like a refuge where I can feel unconstrained.	0.903	0.889	0.819	0.931
	B2 Spending time in this district gives me a good break from my day-to-day routine.	0.905			
	B3 This district let me get away from things that usually drain my attention.	0.907			
Scope	S1 In this district there are few boundaries to limit my possibility for moving about.	0.916	0.813	0.842	0.914
	S2 This district is large enough, with no restrictions to move movements.	0.919			
Fascination	F1 This district is fascinating and charming.	0.851	0.813	0.728	0.889
	F2 In this district like this my attention is drawn to many interesting things.	0.872			
	F3 The landscape in this district awakens my curiosity.	0.836			
Coherence	C1 In this district is easy to move around so that I could any activities I want.	0.844	0.827	0.744	0.897
	C2 This district like everything seems to have its proper place.	0.895			
	C3 The landscape in this district is organized and arranged.	0.847			
	Landscape perception				
Landscape perception	Lp1 Esthetic (beautiful-unattractive).	0.813	0.860	0.589	0.895
	Lp2 Historical (traditional-modern).	0.754			
	Lp3 Unique (ordinary-distinctive).	0.675			
	Lp4 Pleasant (pleasant-unpleasant).	0.784			
	Lp5 Natural (natural-artificial).	0.774			
	Lp6 Safety (safety-dangerous).	0.796			

and support the interpretation of each item, making the questionnaire suitable for further application in structural equation modeling.

In addition, it is worth noting that all indicators exhibited loadings exceeding 0.70, except for Lp3, which had a slightly lower loading of 0.675. However, we retained this indicator since the consideration that weaker outer loadings between 0.40 and 0.70 can be retained if they can explain 50% of AVE (Hair et al., 2019). Besides, to assess discriminant validity, the Fornell-Larcker criterion was employed. This criterion compares the square root of AVE for each construct with the correlations between pairs of latent variables. In this study, all correlation coefficients were found to be smaller than the square root of AVE, indicating an acceptable level of discriminant validity (Table 2).

4.3. Measurement of the structural model

To analyze the path correlations and statistical significance among variables, we used the bootstrapping resampling and blindfolding approach. Specifically, the coefficient of determination values (R^2) was calculated to assess the extent to which the variance of a latent variable is explained by its overall variance (Hair et al., 2019). Acceptable R^2 values for this study were observed for place dependence (0.208), place identify (0.563), and perceived restoration (0.531). To evaluate the model's predictive relevance for each construct, we considered the predictive relevance (Q2), which indicates the effectiveness of each prediction variable. The Q2 values obtained were 0.139 for place dependence, 0.421 for place identity, and 0.326 for perceived restoration. Additionally, the standardized root mean square residual (SRMR) was utilized to assess the suitability of the measurement model's evaluation. In this study, the SRMR value was 0.073, which is below the threshold of 0.08 (Hair et al., 2019). This indicates a good fit between the empirical covariance matrix and the theoretical covariance matrix implied by the model.

4.4. Hypothesis testing

4.4.1. Analysis of path relationships

As shown in Figure 4 and Table 3, standardized path coefficients and their significance indicate the relationships among landscape perception, place attachment, and perceived

TABLE 2 Discriminant validity analysis.

	Landscape perception	Place dependence	Place identity	Coherence	Fascination	Scope	Being away
Landscape perception	**0.767**						
Place dependence	0.457	**0.826**					
Place identity	0.381	0.749	**0.870**				
Coherence	0.555	0.458	0.485	**0.862**			
Fascination	0.552	0.475	0.502	0.734	**0.853**		
Scope	0.575	0.460	0.501	0.733	0.745	**0.918**	
Being away	0.593	0.536	0.534	0.745	0.692	0.745	**0.905**

Bold values depict square roots of AVE for each latent variable.

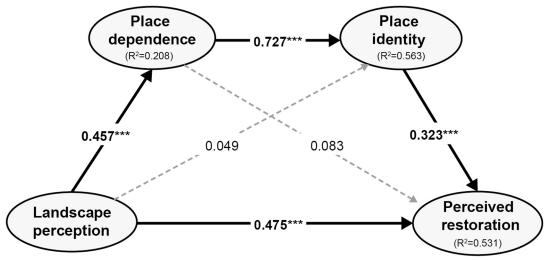

FIGURE 4
Coefficient values of the conceptual model.

restoration. Specifically. H1 was supported ($\beta = 0.475$; $p < 0.001$), meaning landscape perception has a positive impact on perceived restoration. Regarding H2 (H2a and H2b), which aimed to examine the impact of landscape perception on place attachment. It was found that landscape perception showed a positive effect on place dependence ($\beta = 0.457$; $p < 0.001$); thus, H2a was accepted. However, there is no significant association between landscape perception with place identity ($\beta = 0.049$; $p > 0.001$), with H2b was refused. H3 was designed to detect the path relationship between place attachment and perceived restoration. The results indicated that H3a (the influence of place dependence on perceived restoration) was refused ($\beta = 0.083$; $p > 0.001$), while H3b (the influence of place identity on perceived restoration) was accepted ($\beta = 0.323$; $p < 0.001$). H4 was supported ($\beta = 0.727$; $p < 0.001$), which meant place dependence has a direct significant positive effect on place identity.

4.4.2. Analysis of mediating effects

The bootstrapping method was applied to test direct and indirect effects with multiple repetition sampling conditions of 2000 samples. Table 4 shows the results of the direct effects, indirect effects, and total effects. Among these, landscape perception had a direct effect on perceived restoration ($\beta = 0.475$, $p < 0.001$); meanwhile, place attachment showed an indirect effect between landscape perception and perceived restoration ($\beta = 0.161$, $p < 0.001$). Therefore, the mediation path was as follows: 'landscape perception → place dependence → place identity → perceived restoration'. However, the effects of the other two mediation pathways (landscape perception → place dependence → perceived restoration; landscape perception → place identity → perceived restoration) were not statistically significant. That is to say, landscape perception could influence the restorative experience in a direct way. Simultaneously, it can induce feelings of place attachment, which in turn facilitate emotional regulation mechanisms that help escape from mental exhaustion ultimately.

4.4.3. Multiple group analysis

H5 predicted that visitor groups moderate the relationships between landscape perception, place attachment and perceived restoration. Before testing the moderating effect, we used MICOM analysis to detect measurement invariance within the structural model across three distinct visitor groups (Henseler et al., 2015). In this case, we adopted a comparative two-group approach, resulting in three comparisons: long-time residents and short-time residents; long-time residents and transient tourists; short-time residents and transient tourists. According to Henseler et al. (2015), the configural invariance was firstly established, which automatically meted the MICOM procedure in SmartPLS 4.0. Second, we calculated compositional invariance, utilizing the original composite correlation value and the 95% confidence interval as a baseline. The results provided substantial support for compositional invariance (Supplementary Table A1). We then applied a 5,000 permutations test to determine whether the composites' mean values and variances were equivalent (Supplementary Tables A2, A3). In three groups, some permutation variances ratios were outside the 95% confidence interval for the value of the initial differences, leading to the establishment of partial measurement variance.

Multigroup analysis was then performed by comparing the paths across different groups. Path coefficients and significance across visitor groups are presented in Table 5. H5b was supported in terms of the path of 'landscape perception → place dependence', which exhibited a more pronounced effect on long-term residents compared to transient tourists. Besides, landscape perception exerted a weak direct effect on place identity for long-time residents, whereas this effect was non-significant for short-time residents and transient tourists. Thus, the hypothesis H5c was supported. Moreover, the path of 'place dependence → perceived restoration', varied in different groups, exhibiting significance only in the case of transient tourists, thereby supporting H5d. Concerning the relationship of 'place dependence → place identity', long-time residents displayed significantly lower values compared to the other two groups, and hypothesis H5f was supported. Additionally, H5a and H5e were rejected.

TABLE 3 SEM path estimation and significance test.

Hypothesis	Path	Estimate	*T*-value	*p* values	Conclusion
H1	Lp → Pr	0.475***	12.425	0.000	Accepted
H2a	Lp → Pd	0.457***	11.835	0.000	Accepted
H2b	Lp → Pi	0.049	1.478	0.070	Rejected
H3a	Pd → Pr	0.083	1.544	0.061	Rejected
H3b	Pi → Pr	0.323***	6.683	0.000	Accepted
H4	Pd → Pi	0.727***	27.510	0.000	Accepted

Lp, Landscape perception; Pi, Place identity; Pd, Place dependence; Pr, Perceived restoration. **Means *p*-value is significant at 0.05 level, ***Means *p*-value is significant at 0.001 level.

TABLE 4 Direct and indirect effects of landscape perception on perceived restoration.

Effect	Path	Estimate	*T*-value	*p* values	Conclusion
Direct	Lp → Pr	0.475***	12.425	0.000	—
Indirect	Lp → Pd → Pr	0.038	1.512	0.065	No mediated
	Lp → Pi→Pr	0.016	1.429	0.077	No mediated
	Lp → Pd → Pi→Pr	0.107***	5.697	0.000	Partly mediated
Total indirect	Lp → Pr	0.161***	6.234	0.000	—
Total effect	Lp → Pr	0.637***	20.068	0.000	—

Lp, Landscape perception; Pi, Place identity; Pd, Place dependence; Pr, Perceived restoration. **Means *p*-value is significant at 0.05 level; ***Means *p*-value is significant at 0.001 level.

TABLE 5 Path coefficient comparison between three groups.

	LR	SR	TT	(LR – SR)		(LR – TT)		(SR – TT)	
	Path coefficient	Path coefficient	Path coefficient	DI	*p* value	DI	*p* value	DI	*p* value
H5a: Lp-Rp	0.483***	0.487***	0.461***	−0.004	0.485	0.021	0.416	0.025	0.378
H5b: Lp-Pd	0.563***	0.449***	0.330***	0.114	0.078	0.233	**0.017**	0.120	0.138
H5c: Lp-Pi	0.164**	0.015	0.070	0.150	**0.038**	0.095	0.184	−0.055	0.266
H5d: Pd-Rp	0.083	0.044	0.212**	0.039	0.375	−0.129	0.189	−0.167	0.113
H5e: Pi-Rp	0.321***	0.291***	0.344***	0.030	0.393	−0.023	0.419	−0.053	0.324
H5f: Pd-Pi	0.589***	0.769***	0.751***	−0.180	**0.003**	−0.162	**0.024**	0.018	0.398

Lp, Landscape perception; Pi, Place identity; Pd, Place dependence; Pr, Perceived restoration; LR, long-time residents; SR, short-time residents; TT, transient tourists. **Means *p*-value is significant at 0.05 level, ***Means *p*-value is significant at 0.001 level. Bold value means there was a significant difference between the two groups, with p-value is significant at 0.05 level.

5. Discussion and conclusion

5.1. Main conclusion

In our study, we uncovered the association between landscape perception, place attachment and perceived restoration by PLS-SEM, as well as further confirmed the mediating effects of place attachment. By MGA analysis, we analyzed the moderating role of different visitor groups among long-time residents, short-time residents, and transient tourists. Main conclusion from these analyses is described and presented in the following.

Firstly, the landscape perception of visitors in historic districts significantly influenced place dependence. This finding suggests that individuals always rely on their perception of environment to subsequently develop emotional associations. This further confirms the importance of landscape perception as a precursor in developing place attachment. As mentioned by Stedman (2002), place dependence not only sustains emotional ties but also relies on the perception of the psychical environment. In addition, landscape perception did not establish a direct and significant correlation with place identity. This could potentially be attributed to the fact that the formation of place identity requires solid knowledge, familiar understanding, and profound impression, all of which contribute to a sense of belonging (Gu and Ryan, 2008).

Secondly, in this study, as respondents' scores on place identity increased, they were more inclined to perceive restoration. This finding is consistent with the investigation from Liu et al. (2020), who claimed that place identity had a stronger influence on perceived restorativeness than place dependence. Similarly, Kyle et al. (2004) indicated that respondents with a high place identity dimension were more likely to support payment for preserving and restoring the natural environment. These findings further supported the critical role of place identity in the process of place attachment influencing restorative perception.

Thirdly, we found that place dependence and identity as sub-dimensions of place attachment were not entirely uniform. Place dependence significantly influenced place identity in historic districts, demonstrating that the formation of place attachment follows a progressive path from functional to emotional attachment. Although

interrelated, the two dimensions of place attachment represent different elements of the human-land connection. Indeed, when both place dependency and place identity are mentioned, identity tends to develop subsequent to dependence, revealing a more time-dependent feature (Hernández et al., 2007).

Fourthly, the response path of perceived restoration has a direct effect of 'landscape perception → perceived restoration' and a partially mediated effect of 'landscape perception → place dependence → place identity → perceived restoration'. The pathway suggested that landscape perception can directly trigger restorative experience, as well as indirectly contribute to functional dependence and emotional identification, further facilitating relaxation from worries and stresses. Our findings align with several studies that validate the association between place attachment and entertainment (Adevi and Grahn, 2011; Ratcliffe and Korpela, 2016). Arguably, the bonds between individuals and their environment are inherently tied to the perceived restoration.

Finally, our study reveals the moderating effects of visitor groups on the relationship between landscape perception, place attachment, and perceived restoration. As investigated in previous studies, the relationship between landscape perception and restorative perception was influenced by significant differences in place attachment among tourists of different identities (Gu and Ryan, 2008; Trąbka, 2019). In current study, the landscape perception of long-time residents could directly influence place identity. Transient tourists, in contrast, exhibit a significant direct association between place dependence and perceived restoration, indicating that functional dependence is more important for them. These findings supported the concept that place attachment involves a psychological investment in a locale that tends to evolve over time (Halpenny, 2010; Wan et al., 2022). Place dependence is more pertinent for short-time sightseeing, while place identity is essential for the long-time visitor.

5.2. Contribution and implication

5.2.1. Theoretical implications

The theoretical implications of this study are as follows. Firstly, this study established a conceptual model of the correlation between visitors' landscape perception, place attachment and perceived restoration. With urban densification potentially diminishing the access to green recreational spaces, our results validated the restoration potential of historic districts and extended the application of ART in the urban environment. Secondly, our findings confirmed that perceived restoration is a bottom-up process, achieved by utilizing landscape features and manipulating place attachments to ultimately achieve the experience of restoration. More importantly, these results could improve awareness regarding the integration of the concept of human-land bonds into the design process, aiming to create highly restorative settings in urban areas. These findings are also in line with the recommendations of UNESCO on the management of Historical Urban Landscapes (Ginzarly et al., 2019). Thirdly, we examined the significant moderating effect of the visitor category in conceptual model. Consistent with Jutla (2000), tourists' perceptions are influenced by the natural and cultural landscapes, whereas residents' perceptions are shaped by their familiarity with the place. Therefore, concerning and understanding the variations in characteristics among different visitor groups provides an innovative perspective in clarifying the process of mental recovery. This information also appeals more targeted strategies for designing and planning restorative environments.

5.2.2. Management implications

Historical districts enjoy an emerging popularity in China due to their traditional buildings, unique historical accumulation, and diverse cultural connotations. The characteristic of landscape perception identified in our study may provide some practical contributions for urban planners and managers aiming to create appealing presentations of historic districts. Such measures may involve conserving local cultural customs, historic architecture, and symbolic landmarks to present an authentic portrayal. Considerations could also include enhancing the asthetics of street facade, enabling pedestrian safety, and displaying local characteristics to positively aggrandize the landscape evaluation.

In addition, stronger emotional connections toward a place tend to cultivate more positive restorative experiences. Thus, policy managers should formulate strategies that emphasize visitor's emotional resonance and enrich their spiritual experiences. For example, by creating interactive communication space, organizing cultural activities, and celebrating local festivals, visitors can be encouraged to deepen their understanding of local history and shape their unique memory of the place. Such approaches could trigger place attachment, thereby indirectly accelerating the actualization of the restorative potential in historical districts.

Furthermore, our findings provide compelling evidence that different visitor types hold disparate perceptions and emotional evaluations of historical districts. This insight can be leveraged effectively when crafting comprehensive strategies for the development, promotion, and management of historical districts. On the one hand, the development of historical districts should transition from a focus solely on esthetic preservation toward a holistic incorporation of everyday life, prioritizing local culture and fostering resident identification. On the other hand, by integrating cultural experiences into the business landscape and establishing leisurely cultural symbols within the district, which can increase perceptions and satisfaction for transient tourists.

5.3. Limitation and suggestions for further research

As in every study, this study is subject to several limitations. First, we employed four restorative environment characteristics (fascination, being away, scope, and coherence) as the second order manifest variable to assess the overall level of perceived restoration. Future studies can compare these factors as latent variables to facilitate a more detailed understanding of elements that support perceived recovery. Second, we acknowledge that human perception of physical settings is not solely visual; it is also influenced by the sounds they hear, and even more complicated environment they experienced. Thus, we propose further discussion to expand the possible contribution of soundscape or audio-visual interaction on perceived restoration in historical and cultural sites. Third, our investigation was conducted over a short period, however, it's crucial to note that the conditions of the physical environment change long-term over time, much like how the landscape of a historic district might alter with the seasons. Therefore, future research can further apply the conceptual model in contrasting physical environments, which would enhance the multisensory exploration in restoration research. Forth, in current study, we did not specifically examine the potential impacts of demographics as control variables on the overall conceptual model, as it was not the primary research objectives. In future studies, it

would be valuable to group factors such as gender, age, and education for comparative analysis to assess their influence regarding the relationship between landscape perception, emotional attachment, and restorative experiences. Furthermore, our research areas typically belong to residential historical districts. Thus, future studies could explore other types of historical districts, such as commercial and industrial historical districts, to further examine the generalizability of our proposed theoretical model.

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.

Ethics statement

Ethical review and approval were not required for the study on human participants in accordance with the local legislation and institutional requirements.Written informed consent to participate in this study was provided by the [patient/participants' OR patient/participants legal guardian/next of kin].

Author contributions

JiL and HW: conceptualization. JiL and TD: methodology. JiL, JuL, and JT: software. JiL and TD: formal analysis. JiL, TD, and JT: investigation. JiL and JuL: writing—original draft preparation. HW: writing—review and editing. All authors have read and agreed to the published version of this manuscript.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpsyg.2023.1156207/full#supplementary-material

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Perceptions of the health risk from hot days and the cooling effect of urban green spaces: a case study in Xi'an, China

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Background: Hot days are one of the typical threats to human health and sustainable cities. The exploration of residents' perceptions of thermal environment and its mitigation measures will support the health risk prevention.

Methods: A survey with a combination of closed-ended and open-ended questions was conducted in July 2021 among 13 urban parks in Xi'an City, China. With the help of ANOVA and ordinal logistic regression, this study investigated the influencing factors both on residents' health risk perception of hot days and their perception of the effect of urban ecological landscape on reducing the thermal risk. The relationship between health risk perception and residents' needs of urban ecological construction was also explored.

Results: According to 325 valid questionnaires, the male-female ratio of respondents was found to be 1:0.87, young people aged 18-29 (26.46%), the retirees (27.08%) and the ones with undergraduate education (33.23%) were, relatively, the largest groups. The results show that 92.31% of the respondents believed that their daily lives were under the influence of hot days. Housing types, occupation, cooling equipment at work, and outdoor working hours all had a significant impact on their high temperature perceptions. The proportion of respondents who were under a huge health risk and sought medical treatment due to hot days was 30.16% and 44.92%, respectively. Women were 18.52 and 2.33 times more likely to suffer health threats and experience discomforts than men. Furthermore, 73.23% of the respondents believed that the urban ecological landscapes in Xi'an had an enhanced cooling effect in recent years. Compared with the morphological characteristics, residents' recognition of the restriction of landscape's area on its cooling effect was higher, and the residence duration showed a significant influence.

Conclusion: The cooling effect of green spaces and water effectively resisted urban thermal threats, and residents' needs of the urban ecological landscapes was associated with their health risk perceptions of hot days. In the future, it is necessary to promote the early warning of hot days, meanwhile, the optimization of landscape patterns of green infrastructures should be implemented in urban planning for the purposes of residents' health risk prevention.

KEYWORDS

hot days, urban green spaces, health risk perception, cooling effect, Xi'an City

1. Introduction

Against the background of global warming and accelerated urbanization, the increase in urban temperature has significantly exceeded that of the global temperature (1). According to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC), the global surface temperature during 2011–2020 was 1.09°C warmer than that during 1850–1900. As one of the most extreme meteorological events, hot day is an atmospheric process that exerted adverse impacts on human health, urban safety, and the ecological environment (2, 3). In addition, the combination of urbanization and global warming will aggravate the severity of hot days (4). "Good health and well-being" and "Sustainable cities and communities" are the important parts of Sustainable Development Goals (SDGs) of 2030. In recent years, hot days are showing a trend of increasing frequency, intensity, and duration (5), which have seriously hindered the achievement of the SDGs (6). At the same time, ecological landscape construction is considered to be an important natural-based solution (NbS) to urban thermal environmental stress. The cooling effect of urban green spaces and water has been widely confirmed (7, 8), especially the beneficial effects of urban green spaces on the mental and physical health of residents (9). Conducting comprehensive researches on urban thermal risk solutions from the perspective of urban ecological construction and residents' health risk perceptions is a feasible way to build sustainable cities and against public health threats.

Perception of hot days and thermal risk is an important part of public risk perception. Directing attention to the needs of urban residents under thermal environmental risks can provide a reference for the government to formulate reasonable adaptation policies and effective urban ecological construction. International research on hot days perception and adaptation began in the 1980s, and qualitative interviews with vulnerable groups have become the focus in recent years (10, 11). As Chinese society gradually attaches importance to improving the quality of human settlements, relevant studies have attracted more attention (12). The current research mainly focuses on the awareness of high temperature weather and its influencing factors (13, 14), the health risks of hot days (15, 16), the impact of high temperature on residents' behavior (17, 18), thermal risk adaptation (19, 20), mental and physical health benefits from urban green spaces (21, 22), and the mechanism of urban ecological construction promoting public health (23, 24). Conducting questionnaire surveys for specific groups (25), using case-crossover analysis (26), and carrying out a time-series assessment with mortality or morbidity data and meteorological data (16) were the main ways to explore the residents' health risk perceptions and their adaptations. However, there are still certain issues among the existing researches that deserve to be further explored. On the one hand, existing studies on urban thermal risk perceptions has not well integrated with its nature-based solutions, nor has it paid enough attention to the judgment and needs of residents regarding the cooling effect of urban green spaces, thus making it difficult to combine the research results with the improvement of comfort in human settlements. On the other hand, one of the goals of the studies on residents' health risk perceptions should be guide urban ecological construction and create a better living environment. However, there is still a lack of attention on the public cognition of ecological landscape patterns toward the mitigation of hot days. As such, the research on the health risk perceptions from the perspective of landscape ecology needs to be strengthened.

Xi'an is one of the three international metropolises in China. In conjunction with the rapid urbanization, the buildings in the central area of Xi'an are too dense since urban construction is mostly attached to, and overlapped with, historical sites, which aggravates the impact of hot days and thus makes it a "furnace" city (27). Existing studies have shown that the death cases of high temperature in Xi'an increased by 54% in 2010 compared with the same period the previous year (28). Based on the data from 2013 to 2015 on mortality, cities located at middle latitudes like Xi'an was found to have a higher mortality increase under exposure to hot days (29). And an extremely high temperature of 41.80°C on July 24, 2017 in Xi'an has posed great challenges to public health (30). In view of this, against the demand of reducing the human health risks and the construction of sustainable cities, three detailed objectives were defined in this study: (1) to investigate residents' perception of health risk caused by hot days and its influencing factors; (2) to examine residents' perception of the cooling effect of urban green spaces and its influencing factors; (3) to explore how would the residents' health risk perception impact on their needs of the construction of urban ecological landscapes. The results of this study could help to explore the feasible ways to alleviate the human health risk of urban extreme high temperatures, which could also provide a scientific reference for promoting the optimization of human settlement and urban ecological construction in Xi'an.

2. Materials and methods

2.1. Study area

Xi'an City is located in the middle of the Yellow River Basin, with the Qinling Mountains in the south and the Loess Plateau in the north. The geographical location makes it prone to the "foehn effect." Xi'an has a semi-humid continental monsoon climate in the warm temperate zone, with an annual average temperature of 13.10–14.30°C, and an annual precipitation of 528.30–716.50 mm. High temperature is one of the meteorological disasters that occur in Xi'an. Based on the monitoring of national meteorological station in the city (Jinghe Station, located at 34°26'N, 108°58'E in the north of the Weiyang District), the high temperature station frequencies, i.e., ≥35°C, was found to be 139 times in 28 days, 106 times in 20 days, and 147 times in 34 days during 2019 to 2021, respectively. It must be noted that these results increased significantly in 2021. In addition, the most severe hot days in Xi'an also usually occur in July. During 2019 to 2021, the monthly extreme low and extreme high temperature in July ranged from 18–40°C, 17–38°C, and 19–39°C, respectively. During the investigation period of this study, the weather in Xi'an was mainly sunny with the highest temperature being noted as 39°C.

In this study, the six districts (Weiyang District, Baqiao District, Lianhu District, Xincheng District, Beilin District, and Yanta District) were chosen as the study area. These districts are the core areas of population and of urban construction in Xi'an, with a total territory area of 844.50km^2. They are also the place where hot days frequently occur and where the urban ecological parks are concentrated. Based on the cloud-free thermal infrared bands of Landsat 8 OLI/TIRS images, the land surface temperature (LST) was retrieved. Figure 1

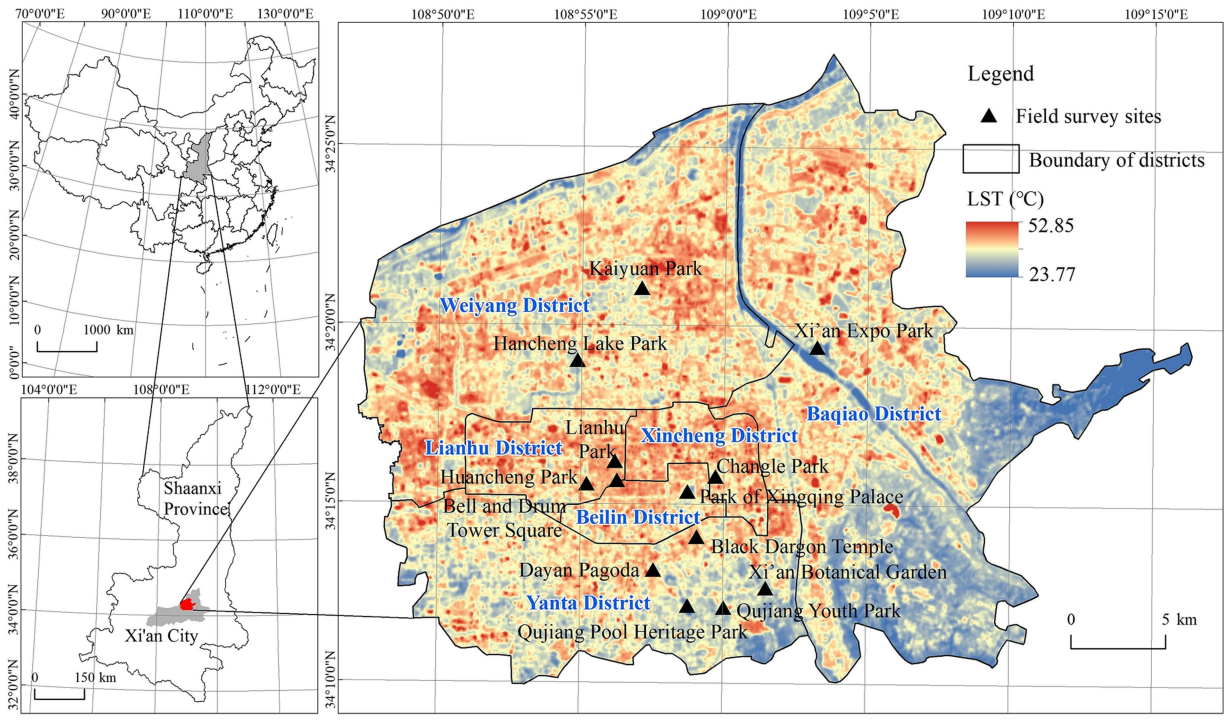

FIGURE 1
Study area and field survey sites.

shows that the LST ranged from 23.93 to 51.02°C and showed an average value of 33.41°C on 13 August 2019 in the study area (31). Low LST values were concentrated in urban water bodies and the undeveloped region in the east of Baqiao District. Based on a comprehensive consideration of location, area, passenger flow, the proportion of green spaces and water landscapes, and construction years, this study took the 13 typical urban parks in the six districts as examples. The selected samples all have high accessibility, high proportion of natural landscapes, and high popularity among residents, thus ensuring the cooling effect of the parks and sufficient respondents during the field survey. Then, field research on urban residents' perceptions of hot days and the cooling effect of urban parks was carried out. The locations of the field survey sites are shown in Figure 1.

2.2. Questionnaire design and field survey

2.2.1. Questionnaire design

In order to achieve the research objectives, this study designed a questionnaire of "Urban residents' health risk perceptions of hot days and the cooling effect of urban green spaces and water landscape," which includes 5 parts and 27 questions (see Supplementary material for the complete questionnaire). The closed-ended questions, open-ended questions and hybrid questions were set during the questionnaire design in this study. The answers of the closed-ended questions were divided into different levels or categories, and the respondents were invited to choose freely within the scope of questionnaires (e.g., the basic information, working and living conditions, and perceptions which needed to describe as degrees). Meanwhile, the open-ended questions focused on the specific evaluation and personal needs of the respondents (e.g., the temperature and duration of hot days, the scores of cooling effect, and the specific suggestions). And the hybrid questions were set to help respondents to supplement the answers that were not considered during the questionnaire design, which was set as the last item in a series of alternative answers in a form of filling in the blanks.

The main contents of the questionnaire included the following: (1) The basic information of the respondents (i.e., gender, age, physical condition, education, occupation, monthly income, and residence time in Xi'an); (2) the details of the respondents' daily life and work (i.e., housing type, cooling equipment at home, working environment, cooling equipment at work, outdoor working hours, and commuting modes); (3) the health risk perception of hot days (i.e., duration of hot days, impact intensity of hot days, specific impact types of hot days, health threat of hot days, and specific types of physical discomfort caused by hot days); (4) the perception of the cooling effect of urban green spaces and water landscapes (i.e., the trend of cooling effect of urban green spaces and water landscapes, whether the area and the shape of landscape affects its cooling effect, as well as the difference of the cooling effect between urban green spaces and water); and (5) the respondents' personal needs and suggestions (i.e., measures that residents want the government to take to deal with hot days, the necessity of building urban ecological landscapes, and other suggestions). Before formally launching the survey, we sent the questionnaire to 7 experts and scholars who have been engaged in the research of urban ecological environment for a long time, and improved the questionnaire according to their suggestions to ensure the rationality and legibility of the questionnaire.

2.2.2. Field survey

In order to reflect the intuitive perceptions of urban residents on hot days, as well as the cooling effect of urban parks comprehensively, this study carried out a field survey in 13 typical urban parks in Xi'an during the period of 10:00–19:00 from July 26 to 31, 2021. During the research period, the weather was sunny, and the maximum daily temperature was mostly above 35°C. Furthermore, the questionnaires were handed out and completed face to face in this study. Respondents were randomly selected to fill out the questionnaires independently, and the investigators were responsible for the guidance. The investigators were trained before the survey that if the respondents were illiterate or unable to fill out the questionnaire independently, then the investigators would dictate the questions and fill in the answers on their behalf. The questionnaire would take about 5–10 min to fill out and which would then be reviewed after the on-site survey. The field survey was carried out during high temperature weathers in the six districts of Xi'an City. The survey objects were the residents in or around the urban parks. In addition, both the survey time and the respondents were representative. A total of 360 questionnaires were sent out in this survey, and 325 valid ones were collected, with an effective rate of 90.28%—excluding those with a rejection rate or omission rate of more than 20%. Around 25 questionnaires were completed in each urban park sample.

2.2.3. Reliability test and validity test

Furthermore, SPSS 25.0 was used to do the reliability test and validity test of the scaled-response questions in the questionnaire. Specifically, the reliability of the data was tested by Cronbach's α coefficient, and the closer it is to 1, the higher the reliability of the data (32). In this study, the Cronbach's α coefficient of all the scaled-response questions was 0.82, and the Cronbach's α coefficients of residents' perception of hot days and the perception of ecological landscape's cooling effect were 0.86 and 0.81, respectively, all of which are greater than 0.80, so the data of the questionnaires had a high reliability. In addition, this study used KMO value and Bartlett's Test of Sphericity for the validity test. The KMO values of all the scaled-response questions, residents' perception of hot days, and residents' perception of ecological landscape's cooling effect were 0.80, 0.84, and 0.78, respectively. And all the Bartlett's sphericity test also passed the significance test ($p < 0.001$), indicating a good validity of the data, and further statistical analysis could be conducted.

2.3. Statistical methods

In this study, the quality control of the questionnaire results was achieved by a double recording method. Then, the SPSS 25.0 software was used for a statistical analysis on the questionnaire results. The methods used in the study included descriptive statistics, the analysis of variance (ANOVA), and logistic regression modeling. Additionally, $p < 0.05$ was regarded as the criterion of statistical significance. All the variables were coded from V1 to V22 and the specific variable assignments could be found in Table 1. The variable assignment rules were based on the classification or sequence characteristics of the answers set in the questionnaire. For instance, categorical variables were numbered according to the order in which they appeared in the questionnaire (e.g., 1 = male and 2 = female for gender), and the sequential variables were numbered from 1 according to the degrees they represented, from low to high (e.g., 1 = barely, 2 = minor, 3 = general, 4 = large, 5 = great for the health threat of hot days). Among the aforementioned, the descriptive statistics aimed to describe the basic characteristics of the respondents, including their basic information, as well as their living and working conditions in summer. ANOVA is the most widely used method of variance testing, the advantage of which is that it can simultaneously examine the significance of multiple indexes and also observe their interaction (33). In this study, the ANOVA was mainly used to judge whether there are statistical differences in the residents' perceptions of hot days, as well as with respect to the cooling effect of urban green spaces and water landscapes among the residents with multiple characteristics. The variables coded from V1 to V13, and from V14 to V21 were taken as the independent variables and dependent variables during the difference analysis, respectively.

The ordinal multi-category logistic regression model is a probabilistic nonlinear regression model, which is suitable for analyzing the relationship between an ordered multi-category dependent variable and multiple independent variables. The independent variable of the model can be continuous or discontinuous, and it is most suitable for the discrete and hierarchical dependent variable (34). In this study, the ordinal logistic regression models with multi-category dependent variables were built according to their continuous characteristics, among which the last category of each dependent variable and independent variable was set as the reference group. To detect the influencing factors of the urban residents' health risk perceptions of hot days (V14-V17) and their cognitions of the cooling effect of urban ecological landscapes (V18, V20, and V21), the basic characteristics of the respondents involved in the survey were taken as the independent variables (V1-V13). It should be noted that V18 was not taken considered in a logistic regression due to the non-continuity. Moreover, the influence of residents' cognition of thermal environment and its mitigation (V14-V21) on their needs of the urban green spaces and water construction (V22) was also identified by the logistic regression model.

3. Results

3.1. Basic characteristics of the respondents

Among the 325 valid questionnaires, there were 174 male and 151 female respondents, with a ratio of 1:0.87. In terms of age composition, young people aged 18–29 (26.46%) and older adult aged over 60 (25.85%) were, relatively, the largest groups. Corresponding to the age structure, retirees (27.08%) and students (23.08%) accounted for more than half of the occupations. The respondents with undergraduate education accounted for the largest proportion (33.23%), followed by high school (secondary specialized school or vocational–technical college) education (25.54%). More than 60% of the respondents were locals who have always lived in Xi'an, and more than half of them had a monthly income of less than 4,000 CNY. The respondents were generally in good physical condition, with 96.61% of the samples reported to be in great or in well condition. The basic attributes of the respondents are shown in Figure 2. Further, a stratification of the respondents' basic information would be helpful to understand their sociodemographic characteristics. Both the respondents under 18 years old (male–female ratio = 2.00) and older adult over the age of 60 (male–female ratio = 1.80) were male-dominated, while, among

TABLE 1 Variables assignment for the ANOVA and logistic regression model.

Variables		Variable assignments
V1	Gender	1 = male, 2 = female
V2	Age	1 = <18, 2 = 18–29, 3 = 30–39, 4 = 40–49, 5 = 50–59, 6 = ≥60
V3	Physical condition	1 = great, 2 = well, 3 = general, 4 = have disease
V4	Education	1 = junior high school and below, 2 = high school, 3 = junior college, 4 = undergraduate, 5 = postgraduate and above
V5	Occupation	1 = public institutions, 2 = company employee, 3 = service industry, 4 = student, 5 = outdoor worker, 6 = retiree, 7 = individual business, 8 = unemployed, 9 = others
V6	Monthly income	1 = under 2000 CNY, 2 = 2000–4,000 CNY, 3 = 4,000–6,000 CNY, 4 = 6,000–8,000 CNY, 5 = over 8,000 CNY
V7	Residence time in Xi'an	1 = local people, 2 = within six months, 3 = six months to two years, 4 = three to five years, 5 = five to ten years, 6 = more than ten years
V8	District	1 = Yanta District, 2 = Beilin District, 3 = Lianhu District, 4 = Weiyang District, 5 = Baqiao District, 6 = Xincheng District
V9	Housing type	1 = non-top floor of building, 2 = top floor of building, 3 = flat building, 4 = villa, 5 = other
V10	Cooling equipment at home	1 = none, 2 = one kind, 3 = two kinds, 4 = three kinds
V11	Working environment	1 = outside in the sun, 2 = outdoor shade, 3 = indoor without air conditioner, 4 = indoor with air conditioner
V12	Cooling equipment at work	1 = none, 2 = one kind, 3 = two kinds, 4 = three kinds
V13	Outdoor working hours	1 = within 1 h, 2 = 1–2 h, 3 = 2–4 h, 4 = 4–6 h, 5 = 6–8 h, 6 = more than 8 h
V14	Influence intensity of hot days	1 = barely, 2 = minor, 3 = general, 4 = large, 5 = great
V15	Influence types of hot days	1 = no influence, 2 = single influence, 3 = multiple influences
V16	Health threat of hot days	1 = barely, 2 = minor, 3 = general, 4 = large, 5 = great
V17	Physical discomfort due to hot days	1 = asymptomatic, 2 = single symptom, 3 = multiple symptoms
V18	Trend of cooling effect	1 = getting better, 2 = not sure, 3 = getting worse
V19	Judgment of cooling ability	1 = green space has better cooling effect, 2 = unsureness, 3 = water has better cooling effect
V20	Landscape's area affects cooling effect	1 = has impact, 2 = not sure, 3 = has no impact
V21	Landscape's shape affects cooling effect	1 = has impact, 2 = not sure, 3 = has no impact
V22	Necessity of urban green space and water landscapes construction	1 = no need at all, 2 = not quite necessary, 3 = general, 4 = necessary, 5 = very necessary

young people aged 18–39 and middle-aged respondents aged 40–59, the proportion of female was slightly higher than that of male. Moreover, respondents' health condition deteriorated gradually during the aging process. Among them, 96.30, 94.26, 92.39 and 80.95% of respondents under the age of 18, 18–39, 40–59 and over the age of 60 were in "great" physical condition, respectively. Judging from the gender structure, the proportion of male in the samples with "great" (53.06%) or "well" (65.00%) health conditions was higher than that of female, and the samples of "have disease" were all concentrated in female. From the perspective of age structure, the groups with "great" or "well" health conditions were concentrated in young people aged 18–39 (39.12%) and older adult over 60 years old (50.00%), respectively.

Differences in the urban residents' working and living conditions, as well as in the cooling measures during summer and commuting modes were found to have a direct impact on respondents' perceptions of hot days. The abovementioned characteristics of the respondents are summarized in Figure 3. In terms of living environment, the respondents mostly lived in a non-top floor of apartment buildings (74.46%), and the cooling equipment at home were mostly air conditioners, refrigerators, and fans. According to the survey, 52.92% of the respondents had all three kinds of cooling equipment, which were qualified to cope with the hot days; however, 0.62% of the respondents did not have any cooling equipment. The residents' working environment could reflect their exposure characteristics in high temperature weathers. More than 70% of respondents worked in air-conditioned rooms and had at least one of the cooling equipment mentioned prior. Further, 48.05% of the respondents worked outdoors for less than 2 h per day in a relatively comfortable working environment. However, there were still 10.39% of them that were exposed to the outdoors for more than 8 h per day. In addition, residents generally used a combination of multiple modes of transportation to travel in summer. Respondents who only traveled by foot or by bicycle (i.e., electric bicycle), shaded public transports, and private cars accounted for 21.85, 12.92, and 6.77% of the total sample, respectively. In addition, the residents who traveled without shelter were mainly the older adult and retirees.

3.2. Difference analysis and influencing factors of the health risk perceptions of hot days

3.2.1. Difference analysis of the health risk perceptions of hot days

Clarifying the urban residents' health risk perceptions of hot days and the differences among the different people groups would help to take appropriate assistance measures for specific groups, thereby

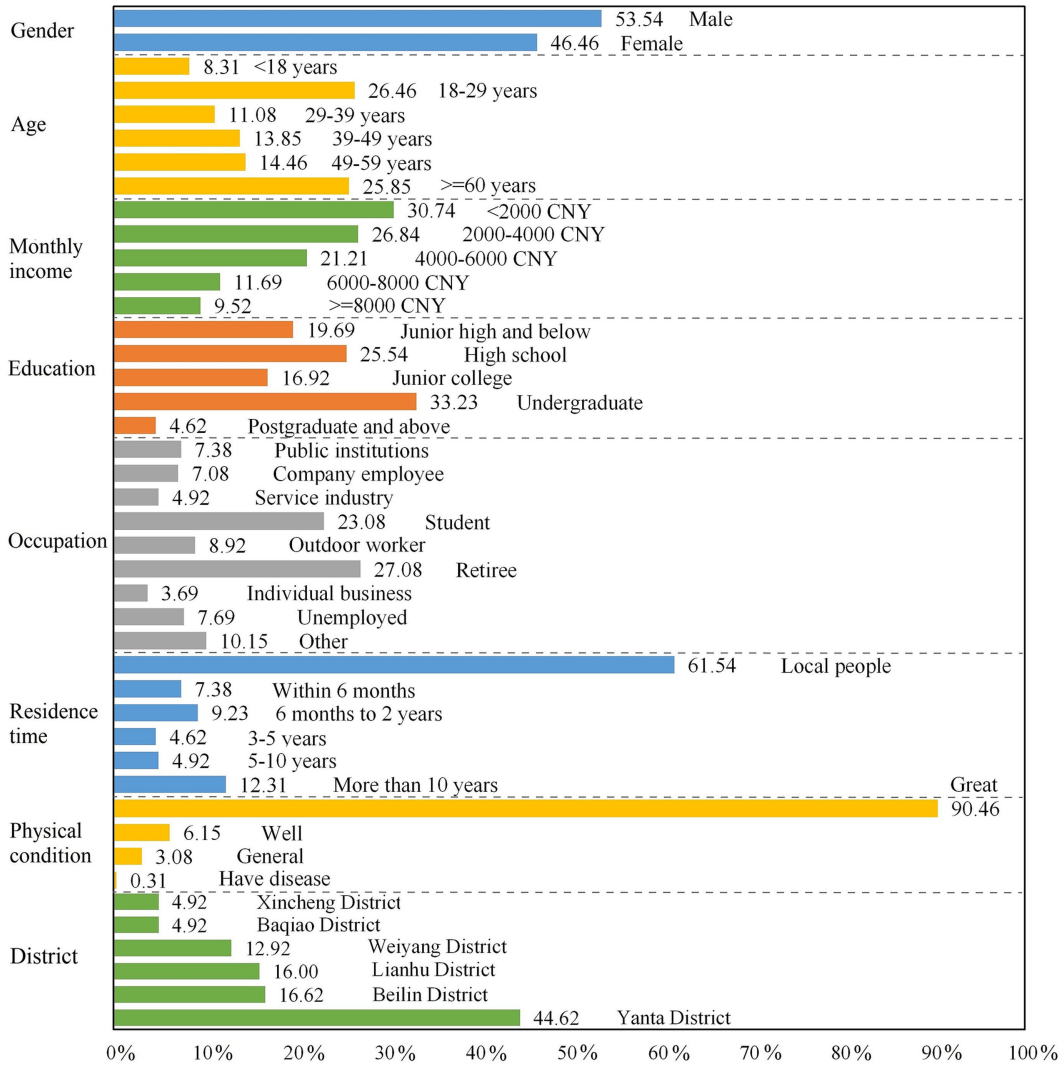

FIGURE 2
Basic information of the respondents.

reducing the health risks of heat exposure. According to the survey, the respondents thought that the high temperature weather was mainly within the range of 24–39°C; having said that, 66.15% of them thought that the hot days were above 35°C. At the same time, 45.85% of the respondents believed that the hot days were concentrated in July and August, and there were also certain residents who said that there was a tendency for them arrive in advance to June and were then postponed in September. The residents' health risk perception of hot days could be detected from four dimensions (Figure 4A), 92.31% of the residents believed that the high temperature weathers in Xi'an had an impact on themselves (including 13.54% for "great influence," 28.31% for "large influence," 36.92% for "general influence," and 13.54% for "minor influence"). Further, 81.23% of the respondents were disturbed to varying degrees in their daily work and life, and 58.46% of them were affected by at least two kinds of disturbance. Specifically, the influence types of hot days were mainly in the form of reduced travel frequency (26.96%), mood swings (17.18%), travel inconvenience (13.13%), decreased study or work efficiency (11.73%), physical discomfort (11.45%), and increased living costs (10.89%) (Figure 4B). Nearly half of the respondents had a moderate perception of the health threat posed by hot days (47.69%), but still over 30% of the respondents declared "great health threat" (8.62%) and "large health threat" (21.54%). Moreover, 44.92% of the respondents had medical treatments due to hot days, among which the frequency of sleep disorders (18.33%), digestive system discomfort (14.62%), or sunstroke (12.06%) was relatively high, some of the respondents showed the symptoms of sunburn (6.96%), respiratory system discomfort (3.48%), and cardiovascular and cerebrovascular complications (3.02%) (Figure 4C).

In this study, the ANOVA in SPSS 25.0 was used to explore the different characteristics among the multiple people groups who are affected by hot days. The basic information and the living or working conditions of the respondents were taken as the independent variables, and their health risk perceptions of hot days were taken as the dependent variables, respectively. With respect to the aforementioned, the test standard was $p < 0.05$. In terms of the group differences in Table 2, urban residents with different working environments and cooling equipment at work showed significant

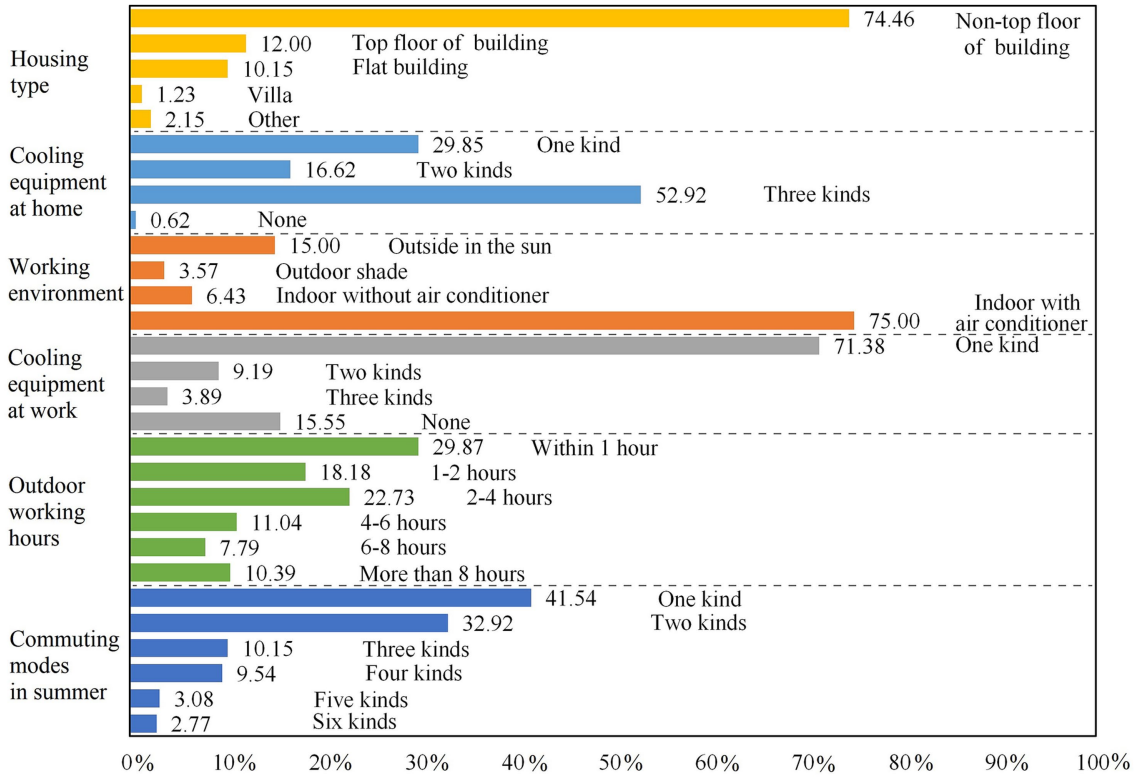

FIGURE 3
Living and working conditions of the respondents.

differences in regard to the influence intensity of hot days on their daily lives. Meanwhile, there was no statistical difference found among the other factors. According to the mean value of the dependent variable, it could be seen that people who work outdoors could feel the influence of hot days more strongly than those who worked indoors. Among them, the people who worked in the outdoor shade had the highest perception degree (Mean = 3.73, S.D. = 1.01), and those who worked indoor with air conditioners were the least affected by hot days (Mean = 3.17, S.D. = 1.07). In addition, the respondents' perceptions of the influence intensity of hot days decreased with the increase in the number of cooling equipment in the workplace. Those with three kinds of cooling equipment (Mean = 2.46, S.D. = 1.29) were significantly less affected by hot days than those with no cooling equipment (Mean = 3.61, S.D. = 1.33), or those who were with only one (Mean = 3.50, S.D. = 1.03) or two kinds (Mean = 3.21, S.D. = 0.99).

It could be found from Table 2 that residents in the different districts showed significant differences in regard to the number of hot days' impact on their daily lives. Since the eastern part of the Baqiao District is mountainous, the urban heat island and threat of hot days are relatively limited. As such, the residents in this district were affected by the least amount of influence types of hot days (Mean = 0.88, S.D. = 0.96). Meanwhile, the more cooling equipment the respondents had at their workplace, then the less they were affected by the specific influence types of hot days. Hot days has widely known as an important risk for death and disease related factors, in this study, the residents from different gender, working environment and duration of outdoor work showed significant differences in their perceptions of the health threat caused by hot days. Women (Mean = 3.41, S.D. = 0.84) were more likely to feel the health threat from hot days than men (Mean = 2.86, S.D. = 0.98); respondents who worked indoors with air conditioner (Mean = 3.04, S.D. = 0.92) were less exposed to health threat from hot days than those who worked outdoors with (Mean = 3.27, S.D. = 1.19) or without shade (Mean = 3.50, S.D. = 1.03), and as the increasing of outdoor working hours, residents' perception of health threat from hot days enhanced significantly. Most of the respondents who worked outdoors for more than 8 h felt that they were exposed to "large" or "great" health threats, while those who were exposed to outdoors for less than 1 h generally felt a "general" or "minor" health threat. Moreover, gender also showed a significant difference in regard to the specific medical treatment due to the impact of hot days for different people groups. Among the various types of physical discomfort, women (Mean = 0.84, S.D. = 0.86) had more symptoms and showed a higher vulnerability than men (Mean = 0.55, S.D. = 0.78).

3.2.2. Influencing factors of the health risk perceptions of hot days

With respondents' basic information and living or working conditions as the independent variables, and their health risk perceptions of hot days as the dependent variables, the logistic regression model regarding the influencing factors of residents' perceptions of hot days was built (Figure 5). The results showed that housing types, occupation, cooling equipment at work, and outdoor working hours significantly affected residents' perceived intensity of the influence of hot days. Specifically, people living on a non-top floor

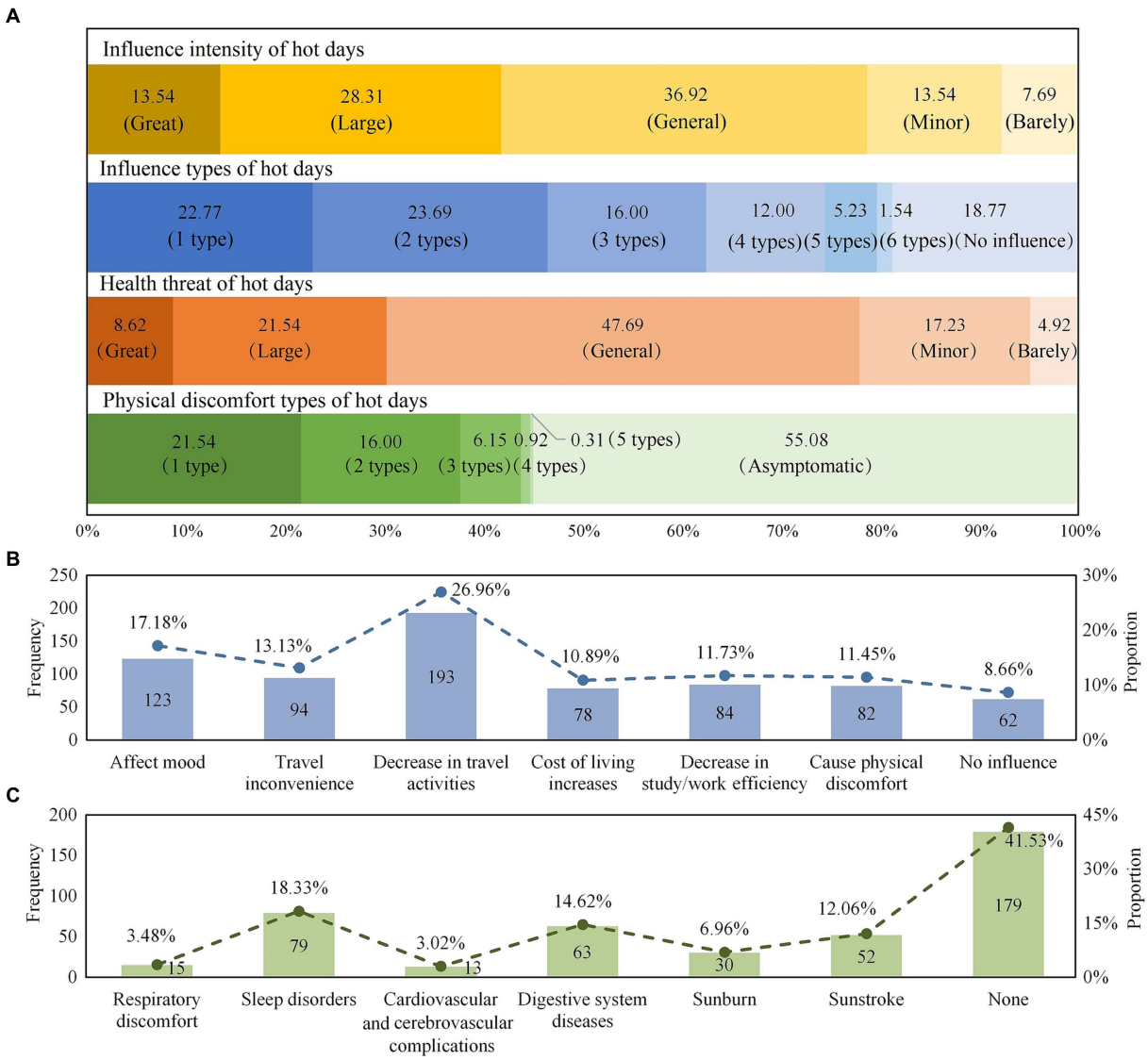

FIGURE 4
(A) Health risk perceptions of hot days, **(B)** the frequency of influence types of hot days, and **(C)** the frequency of physical discomfort types due to hot days.

(*OR* = 0.10, 95% *CI*: 0.01 ~ 0.84, $p = 0.03$) or top floor of apartment building (*OR* = 0.09, 95% *CI*: 0.01 ~ 0.79, $p = 0.03$), and villas (*OR* = 0.02, 95% *CI*: 0.001 ~ 0.67, $p = 0.03$) were less likely to have stronger perceptions of the threat of hot days than those living in other environments (such as prefabricated houses). In addition, the likelihood of residents in the service industry and individual businesses received a strong influence intensity of hot days was found to be 0.19 times and 6.27 times higher in comparison to other occupations (such as freelancers, farmers, etc.), respectively. This fact was deemed to be related to the outdoor exposure time in the different occupations. Respondents without any cooling equipment in the workplace perceived a much higher influence intensity of hot days than those with three kinds (*OR* = 12.21, 95% *CI*: 9.63 ~ 15.48, $p = 0.01$). Residents who worked outdoors for less than 1 h in summer were less likely to perceive the threat of hot days than those who worked outside for more than 8 h (*OR* = 0.18, 95% *CI*: 0.05 ~ 0.66, $p = 0.01$). In terms of the specific impact of hot days, residents with two kinds of cooling equipment at work were more affected than those with three kinds (*OR* = 10.50, 95% *CI*: 7.82 ~ 14.10, $p = 0.04$), which indicating that the combined use of multiple cooling equipment could significantly alleviate the thermal threats on the residents' daily lives.

Figure 5 shows that gender was a significant influence factor both on the health threat and the discomfort symptoms caused by hot days. Men declared they experienced less health threat than women (*OR* = 0.05, 95% *CI*: 0.03 ~ 0.12, $p = 0.001$), in other words, women were 18.52 times more likely than men to suffer health threats from hot days. Meanwhile, men were less likely to seek medical treatment and had fewer symptoms (*OR* = 0.43, 95% *CI*: 0.22 ~ 0.85, $p = 0.02$), which is consistent with the findings in Table 2. Long-term exposure to hot and humid environments could make the ambient temperature exceed the acceptable limit of human, which could directly cause heat-related diseases (i.e., heat cramps, heat exhaustion and heat stroke) (35). This study found that the outdoor working hours significantly affected the perception of heat threat ($p < 0.05$), the longer the

TABLE 2 Differences in the health risk perceptions of hot days for different people groups.

Perception	Category	Type	Mean	S.D.	*F*	*p*
Influence intensity of hot days	Working environment	Outside in the sun	3.59	1.22	2.65	0.05
		Outdoor shade	3.73	1.01		
		Indoor without air conditioner	3.35	1.05		
		Indoor with air conditioner	3.17	1.07		
	Cooling equipment at work	None	3.61	1.33	4.19	0.01
		One	3.50	1.03		
		Two	3.21	0.99		
		Three	2.46	1.29		
Influence types of hot days	District	Yanta District	1.43	0.77	2.65	0.02
		Beilin District	1.46	0.72		
		Lianhu District	1.23	0.81		
		Weiyang District	1.50	0.80		
		Baqiao District	0.88	0.96		
		Xincheng District	1.69	0.60		
	Cooling equipment at work	None	1.69	0.83	2.84	0.04
		One	1.40	0.78		
		Two	1.32	0.55		
		Three	0.91	0.94		
Health threat of hot days	Gender	Male	2.86	0.98	28.76	0.001
		Female	3.41	0.84		
	Working environment	Outside in the sun	3.50	1.03	3.16	0.03
		Outdoor shade	3.27	1.19		
		Indoor without air conditioner	3.11	0.98		
		Indoor with air conditioner	3.04	0.92		
	Outdoor working hours	Within 1 h	2.67	1.03	17.84	0.001
		1–2 h	3.08	0.70		
		2–4 h	3.05	0.66		
		4–6 h	3.17	0.86		
		6–8 h	3.72	1.00		
		> 8 h	4.19	0.82		
Physical discomfort types due to hot days	Gender	Male	0.55	0.78	10.56	0.001
		Female	0.84	0.86		

respondents worked outdoors during the daytime in summer, the higher their perceived health risks from heat exposure.

3.3. Difference analysis and influencing factors of the perceptions of cooling effect

3.3.1. Difference analysis of the perceptions of urban ecological landscape's cooling effect

In this study, the difference in the perception of the landscape's cooling effect was analyzed from the judgment of the trend and ability of the cooling effect, as well as with respect to the impact of the landscape pattern on the cooling effect. The basic information, the living or working conditions of the respondents and their perceptions of the cooling effect were taken as the independent variables and dependent variables for the ANOVA, respectively. The survey showed that most of the respondents were optimistic about the trend of the cooling effect of urban green spaces and water landscapes in Xi'an in recent years (73.23%). However, 20.62% of the residents could not make a clear judgment, and the remaining believed that the cooling effect has diminished (Figure 6). However, there was no statistical difference in the

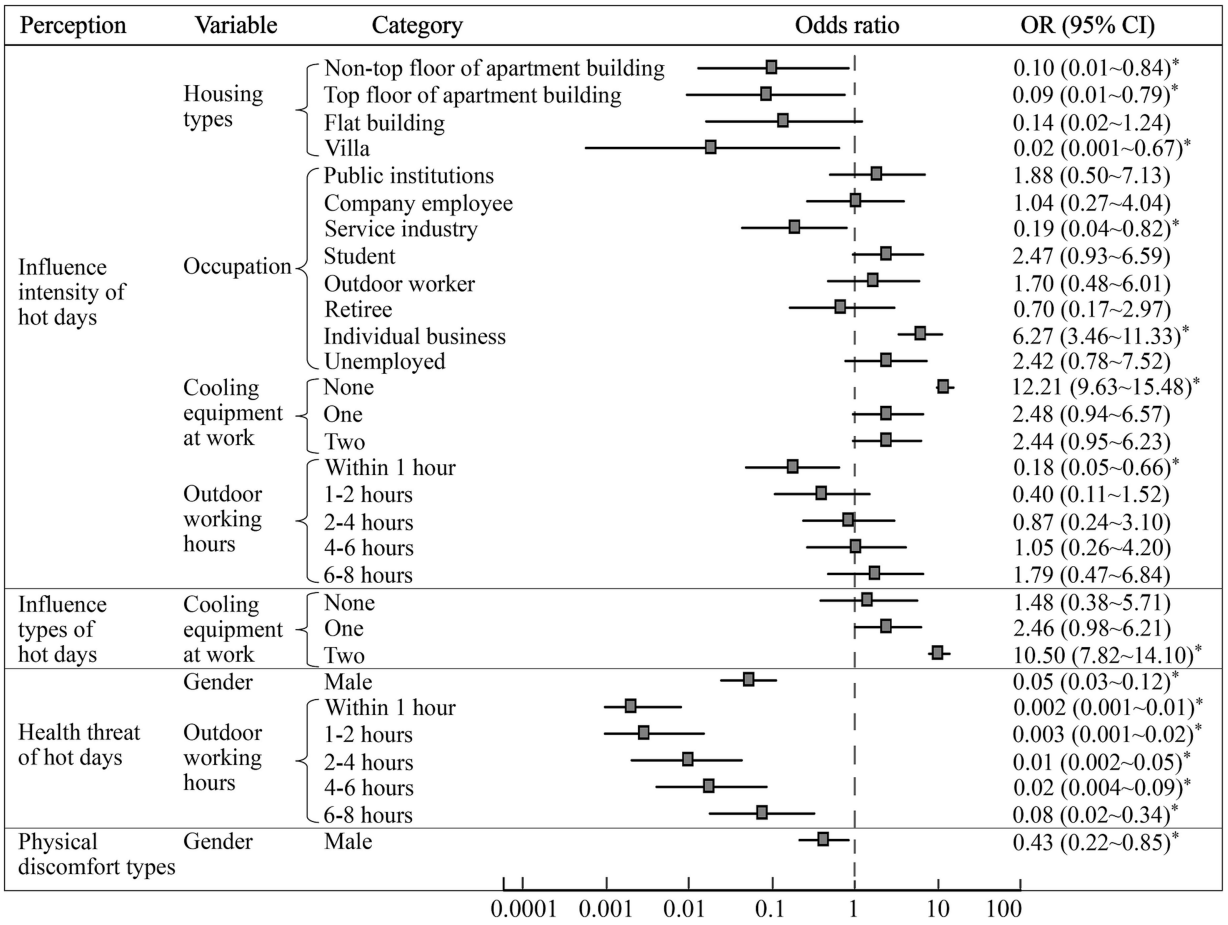

FIGURE 5
Influencing factors of health risk perceptions of hot days (* means $p < 0.05$).

judgment of cooling trend for different people groups through the ANOVA. In terms of judging the difference in the cooling ability between urban green spaces and water landscapes, as can be seen from Figure 6, the proportion of respondents who believed that the cooling effect of urban green spaces is better (43.08%) was only slightly higher than that of who thought water has a stronger cooling ability (41.54%). Table 3 shows that people of different ages had significant differences in judging the cooling effect of urban green spaces and water landscapes. Combining the mean value and the assignment rule of the dependent variable (variable assignment: 1 = green space has better cooling effect, 2 = unsureness, and 3 = water has better cooling effect), it could be seen that people under 30 years old were more inclined to believe that water bodies have a stronger cooling ability (18–29 years old: Mean = 2.43, S.D. = 0.68; <18 years old: Mean = 2.56, S.D. = 0.58). This is related to the fact that the young group always has a wider access to more relevant knowledge and more relevant education, such that their judgment on the ability of the landscape's cooling affect is more accurate.

The respondents had different opinions on whether landscape patterns affected the cooling effect. Residents had a higher acceptance (79.08%) for the restrictive effect of the area of urban green spaces and water landscapes regarding its cooling effect, while only 40.92% of residents believed that the shape of the landscape also had an impact, and another 38.46% held the opposite attitude (Figure 6). In addition, the respondents were invited to rate, on a scale of 0 to 5, the cooling ability of ecological landscapes among different shapes (the higher score means a better cooling ability). The scoring order was in terms of irregular shape (3.76), roundness (3.37), rectangular (3.27), and foursquare (3.08), which is consistent with the results of existing studies, whereby it was found that the more complex the shape of green patches inside a park was then the wider the influence of the cooling effect (36).

The difference analysis in Table 3 shows that residents with different education levels and cooling equipment at work had significant differences in their perceptions of whether the landscape's area would impact its cooling effect. Among them, highly educated people showed a higher degree of recognition of the restrictive effect of landscape area on the cooling effect. At the same time, residents with more types of cooling equipment in the workplace were more inclined to accept that changes in the area of urban parks would affect their cooling effect. It can be seen from Table 3 that residents from different ages had significantly different perceptions of whether the landscape's shape would impact its cooling effect. In addition, their perceptions showed a trend of increasing first and then weakening with older age. Among them, the group who mostly recognized that the shape of the landscape would affect its cooling

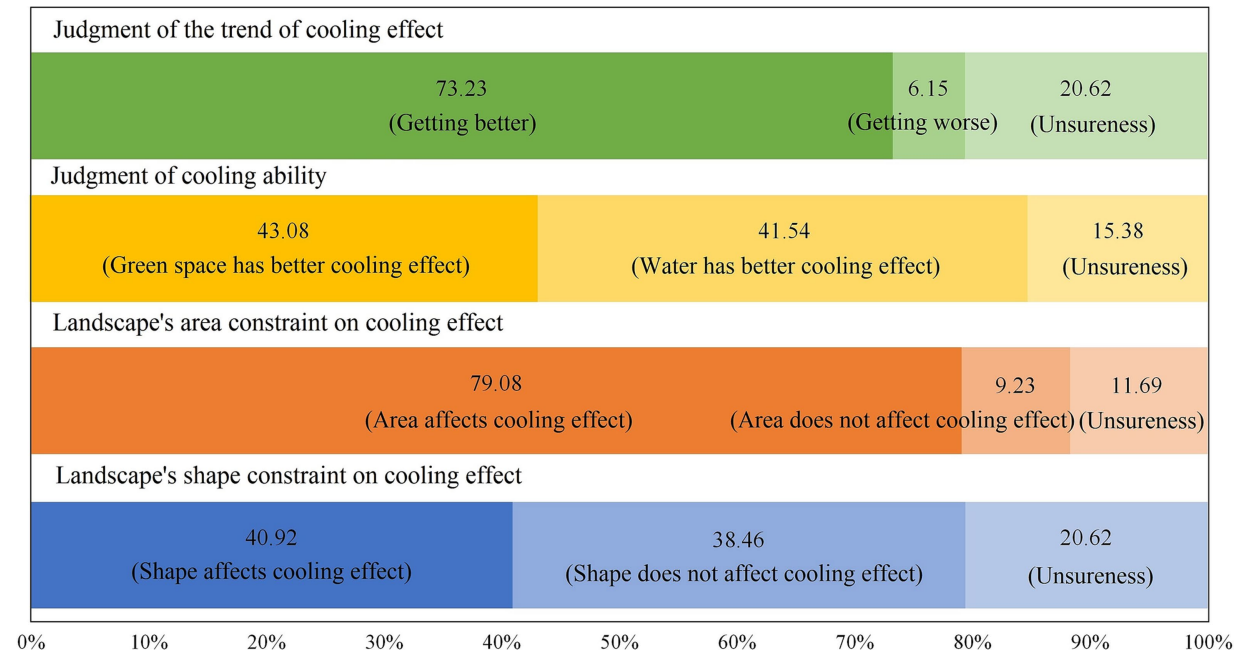

FIGURE 6
Perceptions of the cooling effect of urban green spaces and water landscapes.

TABLE 3 Differences in the perceptions of the cooling effect for different people groups.

Perception	Category	Type	Mean	S.D.	*F*	*p*
Judgment of cooling ability	Age	<18 years old	2.56	0.58	3.14	0.01
		18–29 years old	2.43	0.68		
		30–39 years old	2.06	0.67		
		40–49 years old	2.18	0.68		
		50–59 years old	2.15	0.66		
		≥60 years old	2.19	0.78		
Landscape's area affects cooling effect	Education	Junior high school and below	1.52	0.82	3.88	0.01
		High school	1.53	0.74		
		Junior college	1.33	0.61		
		Undergraduate	1.25	0.62		
		Postgraduate and above	1.17	0.44		
	Cooling equipment at work	None	1.52	0.76	2.79	0.04
		One	1.29	0.62		
		Two	1.12	0.33		
		Three	1.18	0.60		
Landscape's shape affects cooling effect	Age	<18 years old	2.00	0.88	2.83	0.02
		18–29 years old	1.69	0.82		
		30–39 years old	2.00	0.91		
		40–49 years old	2.06	0.91		
		50–59 years old	2.17	0.89		
		≥60 years old	2.17	0.91		

effect was concentrated in the 18–29 years old group (Mean = 1.69, S.D. = 0.82). Meanwhile, the middle-aged (30–39 years old: Mean = 2.00, S.D. = 0.91; 40–49 years old: Mean = 2.06, S.D. = 0.91) and older adult (50–59 years old: Mean = 2.17, S.D. = 0.89; ≥60 years old: Mean = 2.17, S.D. = 0.91) were not sensitive enough to the influence of this topic.

3.3.2. Influencing factors of the perceptions of urban ecological landscape's cooling effect

Figure 7 shows the ordinal logistic regression model regarding the influencing factors of residents' perceptions of urban ecological landscape's cooling effect. It should be noted that respondents' judgment of cooling ability was not taken considered because it is not a continuous variable. It can be seen that residents' monthly income, district, and outdoor working hours had a significant impact on the judgment of the urban parks' cooling trend in Xi'an. Specifically, respondents with a monthly income of less than 2000 CNY were more likely to believe that the cooling effect of parks was getting worse than those with a monthly income of more than 8,000 CNY ($OR = 3.72$, 95% CI: 2.28 ~ 6.07, $p = 0.02$). In addition, who worked outdoors for more than 8 h per day in summer were more likely to believe that the cooling ability of urban parks was enhancing than those who were exposed outdoors for less than 1 h ($OR = 2.81$, 95% CI: 1.55 ~ 5.12, $p = 0.04$). This is because for workers who were always exposed to the outdoors in summer, green parks were important shelters for them when facing the threat of hot days (37), so they are more sensitive to the strengthening of the construction of urban green infrastructure. From a spatial perspective, residents in the Xincheng District showed the most pessimistic attitude towards the cooling trend of urban parks. Respondents in the Beilin District ($OR = 0.16$, 95% CI: 0.03 ~ 0.91, $p = 0.04$) and Lianhu District ($OR = 0.09$, 95% CI: 0.01 ~ 0.77, $p = 0.03$) were less likely than those in the Xincheng District to think that the cooling effect was getting worse.

The residence time in Xi'an and the number of cooling equipment at work had significant constraints on the perception of whether the landscape's area affected the cooling effect. Among them, residents who have lived in Xi'an for more than 10 years were more inclined to give a positive answer to this question than those who had only settled down with the last 3–5 years ($OR = 4.72$, 95% CI: 3.01 ~ 7.39, $p = 0.04$). In addition, respondents without any cooling equipment at work were 5.07 times more likely to disagree that landscape's area had effect on their cooling effect than those who had three cooling devices (95% CI: 3.74 ~ 6.89, p = 0.04). It can be seen from Figure 7 that residents who have lived in Xi'an for 5–10 years were less likely to agree with the constraint of the landscape's shape on the cooling effect than those who have lived in Xi'an for more than 10 years. In addition, the probability that a respondent thought that the shape "has no impact" was 3.63 times than that of the latter (95% CI: 1.99 ~ 6.64, $p = 0.03$). In conclusion, residents with a longer period of residency had a more accurate understanding of the cooling ability of urban green spaces and water landscapes under the influence of landscape patterns.

3.4. Impact of health risk perception on residents' needs of urban ecological construction

Identifying the needs and suggestions of the respondents on urban green infrastructure could improve urban residents' ability to prevent heat risks. In the face of hot weather, residents hoped that the government

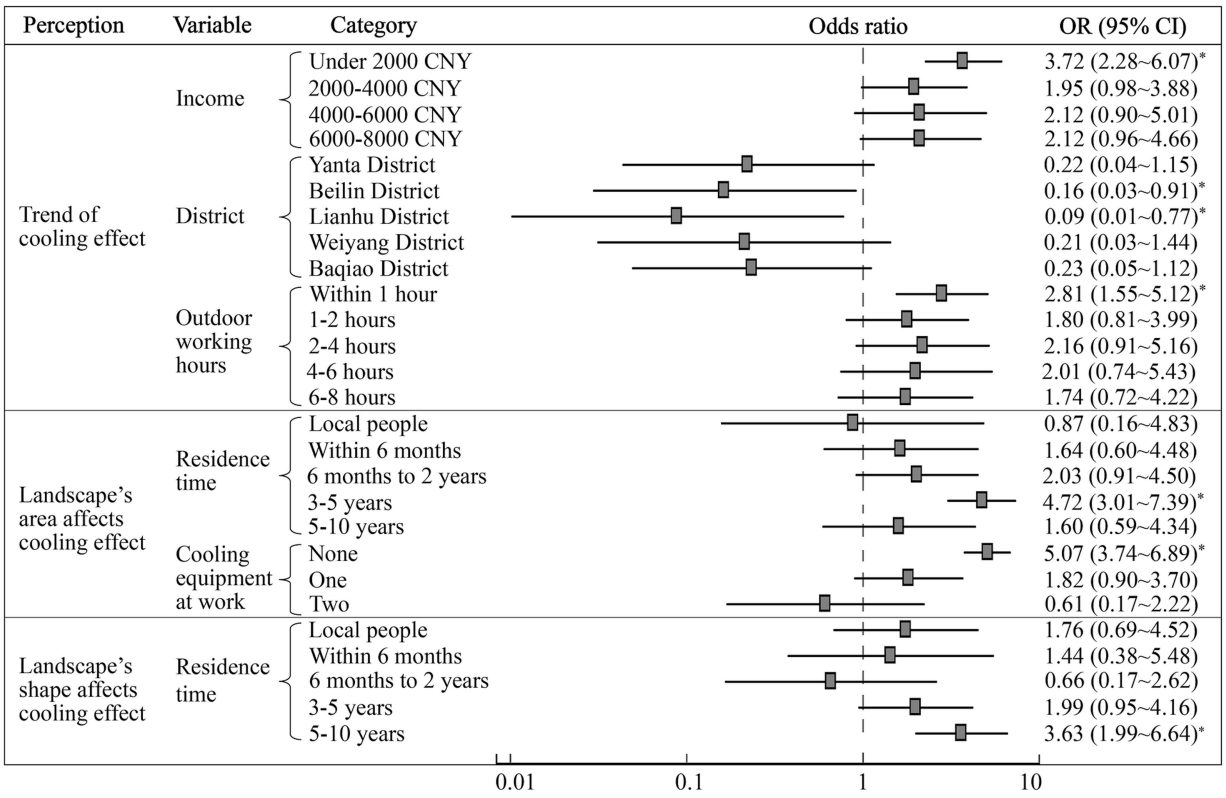

FIGURE 7
Influencing factors of perceptions of the urban ecological landscape's cooling effect (* means p < 0.05).

would take countermeasures, mainly including those related to guaranteeing water and power supply (18.36%), supplementing street trees (18.20%), increasing green infrastructure (16.44%), obtaining the high temperature warnings timely (11.44%), and replenishing air-conditioned public cooling spaces (10.75%). A relatively small number of respondents wanted to adjust working hours in summer, provide heat subsidies to needy families, and provide heatstroke prevention medicines. The results showed that more than 90% of the respondents could recognize the importance of the ecological landscape in mitigating urban thermal risks, and 57.23% of them believed that the construction of more urban green spaces is particularly necessary. More than 50% of the respondents in the Yanta, Weiyang, Lianhu, and Beilin districts were in urgent need for urban ecological landscape construction (Figure 8), among which the residents in the Beilin District thought were "very necessary" accounted for the highest proportion (70.37%).

Residents' needs of urban green spaces and water construction is closely related to their cognition and adaptation to the thermal environment. By taking their ratings on the necessity of green cities as the dependent variable, and their health risks perception from hot days and their understanding of the cooling effect of existing ecological landscapes as the independent variables, an ordinal logistics model between these indicators was built. It could be found that the stronger the perception of influence intensity of hot days, the greater the respondents' needs of the construction of urban green spaces (Figure 9), which was statistically significant ($p < 0.05$). However, the specific impact they received did not significantly related to their needs. In addition, this study found that compared with the respondents who experienced great health threats or who with various physical symptoms due to hot days, residents who thought they were barely threatened ($OR = 0.23$, 95% CI: 0.06 ~ 0.86, $p = 0.03$) or without any discomfort ($OR = 0.29$, 95% CI: 0.12 ~ 0.70, $p = 0.05$) showed significantly lower needs of urban green spaces construction. Figure 9 shows that residents who were optimistic or uncertain about the urban green spaces' cooling trend in Xi'an, their needs of the construction of green infrastructure was 5.63 times and 2.72 times stronger than those who believed that the cooling effect had a worsening trend. Respondents with higher cognition on the constraining effect of landscape pattern on its cooling effect were also more inclined to strongly support urban ecological construction. However, the judgment of the cooling ability between green spaces and water did not affect whether they supported urban ecological construction.

Among the specific suggestions for the urban ecological construction, the respondents generally hoped to increase the number and range of green infrastructure, as well as desired to improve the practicality and ornamental value of green belts. Thus, while providing shade for residents' outdoor activities, these measures could also establish a green image for the city. In terms of urban water construction, the respondents suggested strengthening the layout optimization and water quality of rivers and lakes in Xi'an, especially proposed to strengthen the manual management of urban green spaces around water bodies, the existing research has provided that the cooling effect of water was affected by the proportion of surrounding green spaces, which could produce synergistic cooling effect (38). By doing this, the aesthetics and practicality of urban water bodies in terms of truly developing a cooling effect via the water landscapes could be combined.

4. Discussion

4.1. Comparison with existing studies

In terms of residents' health risk perceptions of hot days, this study found that residents with a relatively poor living environment were likely to have stronger perceptions of the threat of hot days, in

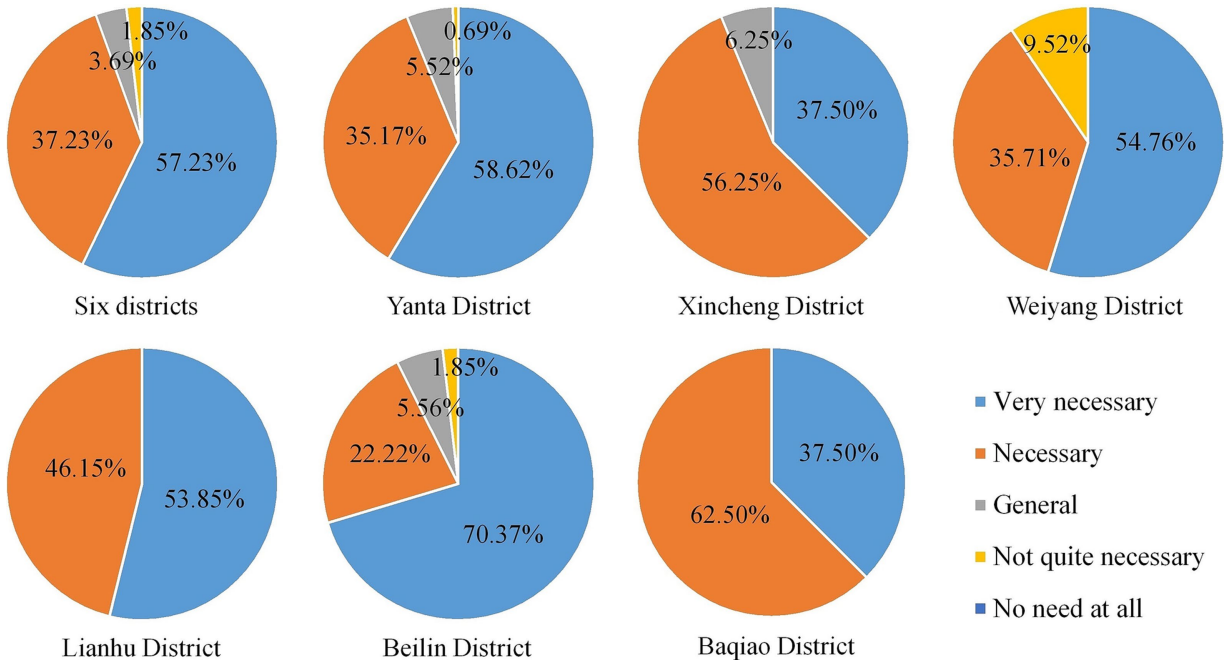

FIGURE 8
Necessity of urban green spaces and water landscapes construction.

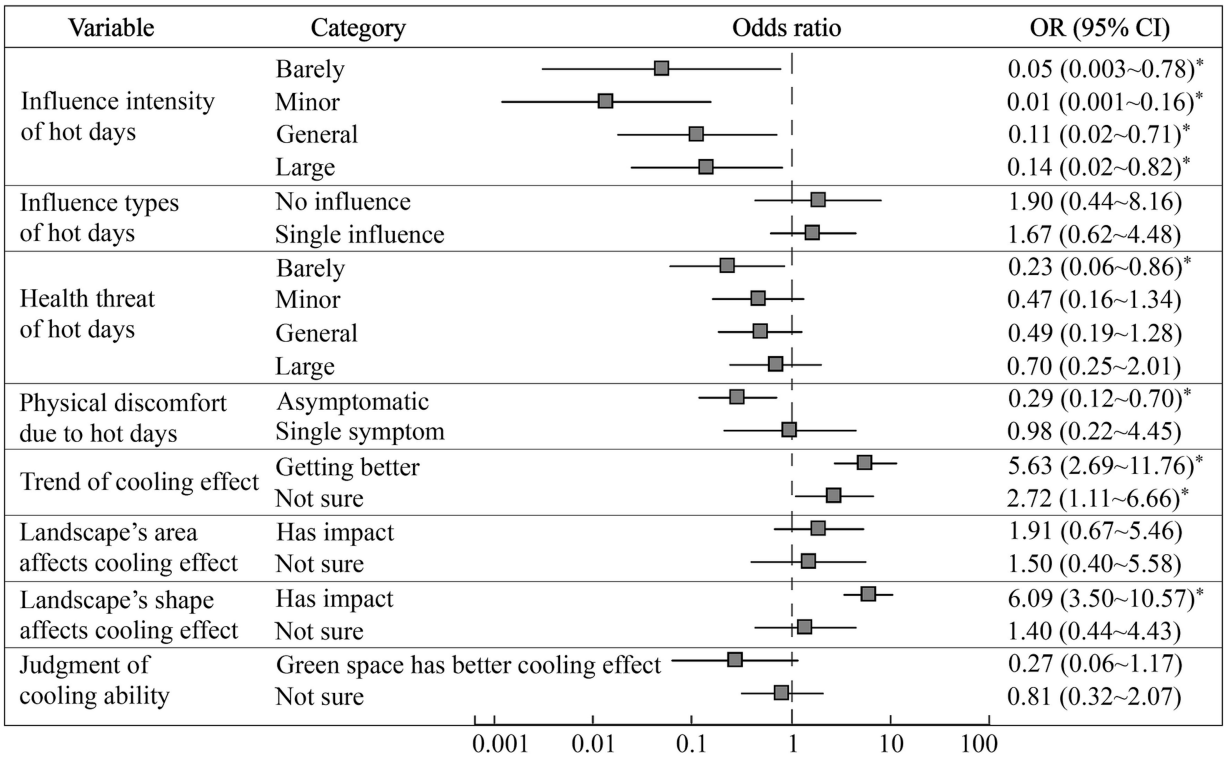

FIGURE 9
Influencing factors of residents' needs of the urban green spaces and water construction (* means $p < 0.05$).

other words, they could be more vulnerable to hot days, which was consistent with the existing research (39). The living environment is an intuitive reflection of a residents' income, and is closely related to the cooling measures taken in the face of heat waves, as well as in their ability to purchase cooling equipment at home, which, in turn, has a significant constraint on their high temperature perception. In addition, this study found that residents' educational background also significantly constrained their cognition, which has also been confirmed in existing studies. Toan et al. noted that for people living in slums and non-slum areas, there was a positive correlation between the education of respondents and their perceived influence level of hot days (40). Furthermore, significant gender differences in residents' exposure to high-temperature health risks was found in this study, this phenomenon was also been proved. Yu et al. found that the effects of high temperature on mortality were modified by gender, of which the harmful effect among women was more than 20 times that among men (41). Therefore, special attention should be paid to the health of women, especially pregnant women and young children under the threat of high temperature risks.

Exploring residents' perceptions, needs and suggestions on the cooling effect of urban green spaces and water bodies is one of the important solutions for urban thermal risk prevention. This study found that, compared with water bodies, the proportion of residents who believed that green space had a better cooling ability was relatively higher. While, existing studies have shown that the cooling amplitude and cooling intensity of water was more advantageous than that of urban green spaces within the same area (42). The major reasons for this perception bias are the relative lack of urban natural water and the small area of water bodies in urban parks in Xi'an City, as well as the fact that the respondents answered without a clear cognition of this question. Existing studies have proved that there was a nonlinear correlation between landscape patterns and urban heat islands (43), and the mechanism of landscape's shape on its cooling effect was more complex than that of area (44). However, the respondents in this study still showed a lack of awareness regarding this phenomenon, which reflected the necessity of strengthening the popularization of relevant knowledge and to the urgency of further deepening the research on the correlation mechanism between landscape patterns and urban thermal environments.

Duan et al. declared that the users of urban green infrastructure generally believed that the high temperature and health risk could be mitigated by urban green spaces (45). At the same time, urban residents prefer multi-functional urban green spaces (46), and the lack of green landscapes in the living environment will increase their willingness to relocate (47). At present, residents' thermal risk perception has attracted much attention, but one of the goals of which is to guide urban ecological construction and create a better settlement environment. Meanwhile, urban planning in rapidly urbanizing areas is still mainly guided by the needs of socioeconomic development, and the limited ecological land puts forward higher requirements for reasonable planning oriented to residents' perceptions and suggestions. Based on the research on the thermal risk perception of urban residents, this study expanded the analysis of their perceptions of urban ecological construction, which promoted the comfort of urban residents to get more attention, and also provided a reference for the development of related research.

4.2. Interaction between air pollution and hot days

With the continuous acceleration of urbanization, air pollution has become another important factor threatening residents' health and urban environment besides hot days. Typical urban air pollutants include PM2.5, SO_2, NO_2, and O_3, for every 10 μg/m^3 growth of which, the mortality rate of people from non-accidental and cardiovascular diseases would increase significantly (48). Xi'an City has a subhumid continental monsoon climate and is located in the plain area, where air pollutants are not easily dispersed in winter and spring. Moreover, with the coal as an important local energy consumption, frequent air pollution incidents have occurred in Xi'an in recent years. A study in Xi'an found that for every 10 μg/m^3 increase in short-term atmospheric PM10, SO_2, and NO_2 concentrations, the number of outpatient visits for schizophrenia increased by 0.29, 1.37, and 1.88%, respectively (49). In terms of residents' perceptions, Orru et al. built a model that describes interrelations between air pollution, health risk perception, health symptoms and diseases (50), and Noël et al. carried out a review analysis of the qualitative research about public health risk perceptions on air pollution (51).

Previous studies have shown that there is a close interaction between urban thermal environment and urban air pollution. Among them, the temperature difference between the central urban area and the suburbs affects the atmospheric circulation, transport and deposition of pollutants, resulting in the reduction of air pressure and the backflow and accumulation of pollutants (52). At the same time, regional differences in pollutant concentrations would also affect the internal radiation of cities, thereby restricting the intensity and pattern of the thermal environment (53). The interaction between them is also an important factor leading to the increase of diseases and mortality of urban residents. A study on 9 European cities pointed out that high temperature caused more deaths when PM10 concentration increased (54), and Schaefer et al. (55) combined the investigation of pedestrian perception on local heat stress and air quality as well as the remote sensing data, and analyzed the regulation path of local microclimate (55). Air pollution was not considered in the questionnaire, which is the limitation of this study. Considering the typicality of urban thermal environment and air pollution in Xi'an, combining the interaction of the two on residents' health perception and their adaptations would be the focus of future researches.

4.3. Impact of questionnaire design on research results

At present, questionnaire survey has become an important approach to carry out researches on health risk perception of urban residents. Questionnaire design is a comprehensive reflection of interviewers' research objectives, and whether the structure and question setting are reasonable would also have a direct impact on the interpretation of the results. According to the difference in question setting, the questionnaire could be divided into three categories. Among them, the closed-ended questionnaire means that the respondents could only choose from the listed answers. It is conducive to the respondents' effective and rapid response, reduces the time cost, and has obvious advantages in the statistical analysis and summary of the results (56). However, the closed-ended question also makes it difficult for respondents to exert their subjective initiative effectively, and would be easy for them to answer some complicated questions randomly. In contrast, open-ended questionnaires do not set standard answers, and respondents could answer according to their own understanding. It has the advantage of being flexible and diverse, which is conducive to obtaining the innovative thoughts of the respondents. However, open-ended questionnaires are difficult to analysis quantificationally and usually time-consuming, respondents tend to be reluctant to think deeply due to boredom, thereby reducing the validity of the questionnaires (57). Hybrid questionnaire makes up for the shortcomings of them, questions that could be answered clearly are usually set as closed-ended, while innovative questions (e.g., suggestions and opinions) are mainly open-ended.

The questionnaire used in this study is of a hybrid type. Among them, most of the objective questions (e.g., basic information, working and living conditions) were closed-ended. For the perceptual questions that required a description of the degree, the respondents were invited to choose in the form of a five-level Likert scale. At the same time, questions about the specific temperature and duration of hot days, the scores of cooling effect for urban green space in different shapes, and the needs and suggestions were open-ended. In addition, this study also set up some hybrid questions to help respondents to supplement the answers that were not considered during the questionnaire design. It should be pointed out that since the field survey in this study was carried out during the hot days in summer, the number of open-ended questions was controlled considering that the respondents tended to refuse to answer due to the high temperature. However, understanding the diverse thoughts of urban residents is pivotal to improve the depth of research.

Therefore, in the further studies, the investigators would adjust the questionnaire design and increase the number of open-ended questions based on this survey. In order to avoid the boredom of the respondents, a combination of recording and keyword response could be used. Specifically, for respondents who are unwilling to directly fill in the open-ended questions, they can be invited to give an oral account of their opinions, and the investigators would make a recording them for subsequent analysis after obtaining their consent. The keyword response is to invite the respondents to fill in several keywords generated by their first reaction, so as to depict a visual map of the respondents' thoughts based on the big data technology. At the same time, the residents' health risk perception due to hot days in Xi'an is a topic worthy of long-term tracking. The regular investigations and the constantly optimization of the questionnaire design would be conducted in further studies, so as to establish a continuous and dynamic investigation database.

4.4. Limitations

Based on the perceptions of residents against the background of urban thermal environments, this study highlighted the direct needs of urban residents, which could effectively support urban planning for the improvement of the quality of living environments. However, there is still room for further improvements in this study. In terms of data and sample selection, due to manpower constraints in the survey, the samples only covered 13 typical urban parks in Xi'an City. In a further study, more comprehensive results could be obtained by expanding the survey scale. At the same time, the construction of ecological landscapes is an effective and necessary approach by which to alleviate hot days. The cooling effect of urban parks is closely related to climate change, urban green

infrastructure planning, and relevant government policies (58). Residents' perceptions of hot days and the cooling effect of landscapes will also change dynamically. Therefore, the long-term monitoring should be the future direction of this study, so as to form practical guidance and suggestions for urban construction in Xi'an. In terms of the mechanism analysis, this study explored the differences in the residents' perceptions and the corresponding influencing factors that were relied upon in the statistical methods. The interpretation of the internal mechanism of the relationship between landscape patterns and thermal environment needs to be strengthened. Whether the relevant conclusions could be applied in other regions needs to be verified by more case studies in the future.

5. Conclusion

In terms of aiming at the construction of sustainable cities against the background of human health risk prevention, this study investigated the influencing factors of residents' health risk perceptions of hot days as well as their cognition regarding the cooling effect of urban green spaces, the relationship between health risk perception and residents' needs of urban ecological construction was also explored. The results showed that most of the respondents believed that the hot days in Xi'an had an impact on them. Housing types, occupation, cooling equipment at work, and outdoor working hours were the significant factors affecting the perception of the intensity of hot days. Specifically, the outdoor workers, residents with relatively poor living environments and with no cooling equipment at work felt more threatened by hot days. Further, gender was found to be a significant influence factor both on health threat and heat-related physical discomfort. Women were more likely to suffer health threats and discomfort symptoms, and usually show a higher vulnerability under the urban thermal risk than men. In addition, the longer the respondents worked outdoors during the daytime in summer, the higher their perceived health risks from heat exposure.

Furthermore, 73.23% of the respondents believed that the cooling effect of urban ecological landscapes in Xi'an has been strengthened in recent years. Monthly income, residential districts, and outdoor working hours were significant influencing factors for their judgment. Workers with longer outdoor exposure were more inclined to believe that the cooling effect of parks was improving. Moreover, relatively more respondents thought the cooling effect of urban green spaces was better than that of water bodies. In terms of landscape patterns, residents who have lived in Xi'an for a longer period tended to agree that the area and shape would affect landscapes' cooling effect. Respondents showed high acceptance regarding the restrictive effect of landscapes' area on the cooling effect, most of them were highly educated and had a variety of cooling equipment at work.

Residents' health risk perception of hot days showed significant impact on their needs of the urban ecological construction. Compared with the respondents who's mental or physical health were barely threatened by hot days or without any discomfort, the needs of urban ecological construction of whom experienced great health threats or with various symptoms was 4.39 times and 3.51 times, respectively. At the same time, respondents with higher cognition on the constraining effect of landscape pattern on its cooling effect and more optimistic about the cooling trend were also more inclined to strongly support the construction of green cities. However, this study showed that residents in Xi'an City still lacked awareness regarding the mitigation effect of urban thermal environments from the perspective of landscape ecology. Therefore, the following work need to be strengthened in the future. First, to improve the accuracy of the early warnings of hot days, targeted education on health risks and protection from hot days should be popularized for older adult, women, and outdoor workers. Second, to improve residents' attention and cognition on the cooling effect of urban parks through multiple media, to guide them to take effective travel modes and cooling measures in the face of heat risk. Third, based on residents' urgent needs for establishing green cities, the close com bination of landscape ecology and urban planning should be further enhanced to promote the construction of a more sustainable and livable city in Xi'an.

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.

Author contributions

TZ and RH contributed to conception and design of the study. MY and XM organized the database. RH, GL, and XW performed the statistical analysis. TZ wrote the first draft of the manuscript. MY, GL, XW, and QH wrote sections of the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1211164/full#supplementary-material

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Targeted health promotion with guided nature walks or group exercise: a controlled trial in primary care

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Background: Contact with nature promotes wellbeing through diverse pathways, providing a potential way of supporting health especially in primary care, where patients commonly suffer from multimorbidity and poor general health. Social prescribing is a non-pharmaceutical approach for improving health as well as social inclusion. This field study explores and compares the effects of a nature-based and an exercise-based social prescribing scheme on mental wellbeing and sleep, in a primary care population.

Methods: Primary care patients identified to benefit from a general improvement to their health were recruited by nurses, doctors, or social workers to this non-randomized, intention-to-treat, pilot field-study. Participants ($n = 79$) chose between the group interventions, either taking part in guided walks in nature, including immersion in a forest with high biodiversity, or participating in a versatile sports program. Mental wellbeing was assessed with the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS), with additional questions evaluating self-rated health and sleep. Impact on mental wellbeing was explored in relation to perceived health. The amount and quality of sleep was measured with wrist-worn accelerometers. With a focus on everyday life impacts, the assessments took place before and after the 8-week intervention. All participants lived in Sipoo, Finland, an area with abundant accessible green space.

Results: Participants (mean age 57 years, 79% female) rated their general and mental health lower than the general population. Participation in the Nature-group resulted in improved mental wellbeing (change in WEMWBS by 3.15, $p = 0.008$), with a positive change for feeling relaxed, being cheerful, having energy to spare, feeling able to deal well with problems, feeling good about oneself and feeling close to other people. The Sports-group was beneficial for those initially rating their health as good. Sleep duration improved in the Sports-group, while participants in the Nature-group reported better sleep quality. Following the interventions there was improvement in perceived health and ability to function in both groups, while perceived mental health improved only in the Nature-group.

Conclusion: We attest that even in areas surrounded by greenery, active interventions can further improve health in a primary care population, and that nature-based interventions are beneficial for those in poor health.

Clinical trial registration: ClinicalTrials.gov, Identifier NCT05893212.

KEYWORDS

green space, mental wellbeing, sleep, primary care, social prescribing, exercise, nature-based interventions, health promotion

1. Introduction

Managing and increasing accessible green spaces has been recommended as a potential way of improving public health (1, 2), while simultaneously responding to the loss of biotopes and biodiversity in a world that is rapidly becoming more urban (3–5). However, how and when nature could be utilized as a treatment for specific diseases or health issues is unknown (2, 6–8). As the natural environment is a varied concept, the type of biotope and the amount of biodiversity, green or blue space, as assessed with the normalized difference vegetation index (6), as well as the type of activity undertaken, must be considered when examining health outcomes (9). Using nature-based interventions as a part of medical treatment and rehabilitation is an evolving and potential method of improving both individual and public health (8). Nature-based social prescribing, also called green social prescribing, allows health professionals to refer clients or patients with particular needs to facilitated nature-based intervention, often in groups (10, 11).

Studies exploring the effects of nature-based social prescribing are still uncommon (8). Growing evidence supports the use of nature-based interventions in improving mental health in adults based in community, but there is less evidence on improved physical health (8, 12). When prescribing nature-based interventions we need to be explicit about who they benefit, as well as how and when, especially if interventions are funded and provided by national health systems. There is a lack of studies assessing patients with multiple morbidities, i.e., those with two or more chronic diseases or sense impairments (6, 13). Multimorbidity is common in those utilizing primary care, especially among frequent users (14). Multimorbidity is known to reduce quality of life and mental wellbeing (15), it has been recognized that there is a need to develop effective interventions improving outcomes (13). There is an increasing understanding that perceived health and positive mental well-being are independent predictive factor for health outcomes (16, 17).

Healthier sleep is associated with better mental wellbeing (18), making sleep an important factor to consider when studying effects of nature-based interventions on mental health. Poor sleep correlates with chronic pain and prolonged sick leave (19), both of which are common presentations in primary care. Insomnia is a condition that is overlooked but it increases the risk of adverse health outcomes and the use of potentially harmful drugs (20), while difficulty falling asleep is associated with increased all-cause mortality in middle-aged and older populations (21).

Our study aims to:

1. explore and compare the effects of a nature-based social prescribing scheme and an exercise-based social prescribing scheme on mental wellbeing in a primary care population,
2. analyze general and mental health outcomes as well as sleep characteristics in a primary care population participating in social prescribing schemes, and
3. test if the effects on mental wellbeing of two different social prescribing schemes are different based on participants general health or mental health status.

2. Methodology and material

2.1. Study design

This is a controlled pilot field-study on parallel groups in an intention-to-treat setting. Participants were recruited from the population using the Health and Social Service Centre of Sipoo and all live in the municipality of Sipoo. Although situated only 17 km from the city center of Helsinki, the capital of Finland, Sipoo is a rural area with abundant green and blue spaces. The population density is 65 persons/km^2 (22). There is an active political will in Sipoo encouraging the use of green spaces for recreation, and the accessible national park of Sipoonkorpi lies in the area. It is likely that participants in the study spend time outdoors and they have easy access to the natural environment. The air quality in the area is generally very good (23). Participants were recruited among primary care patients by nurses or medical doctors, or among social service clients by social workers. Enrolment was not based on a diagnosis, but staff were instructed to identify clients they felt could benefit from a targeted health intervention and to involve in particular those in poor general health. The project was also described in the local media. Adults who were able to slowly walk approximately 2 km could join the study. All the participants were referred to the study by health professionals and were provided information on the groups before choosing between either the Nature-group or the Sports-group. Although the reason to refer was not reported, enrolment in either intervention was a part of real-life treatment.

The intervention program adapted in this study was developed during the Terveysmetsä (transl. Health Forest) project, a national network project established in 2014 (24, 25). Since 2015 two nature guides, who are not medically trained, have organized 8-week rehabilitation programs for patients who frequently visit the health center in close co-operation with a team of doctors and nurses. The positive response gave rise to a need for a more systematic evaluation on the impact of the program, resulting in this study. The living premises were the same for both groups and did not change through the study.

The Nature-group program included learning more about local outdoor areas and nature itself, the biotopes visited were chosen to provide varied nature experiences, including forests, farmland, lakes, and seashore. Accompanied by nature guides the group practiced simple sensory exercises that enhance contact with nature and its microbiome. A more detailed program is attached in Supplementary Data.

The Sports-group participated in an exercise program and met weekly in community sports facilities. Exercise we define as a planned, structured, repetitive, and purposeful form of physical activity that aims to improve or maintain one or more components of physical fitness. The sports program was planned and executed by professional sports instructors in cooperation with health professionals and included both aerobic and anaerobic exercise as well as team sports. The content of the exercise program was planned according to current best practice and considering the participants physical ability. Details of the program are attached in Supplementary Data.

The intensity and duration of the physical activity as well as the social interaction were designed to be as alike as possible in the compared groups. Both groups were offered a meal or snack during or after the session, with the aim of increasing cohesion. The intervention was free of charge, but travel expenses (mostly by car or bus, <10 km) were not covered. With a maximum of 20 participants the groups met 7 times during an 8-week period. Every session took place in a different location. This enabled the participants in the Nature-group to become familiar with the different outdoor areas, and the Sports-group to become familiar with local sports facilities. The planned activity level was modest, equaling approximately 2 km of walking at slow pace. The intervention started in 2018 and was planned to go on until 2020, including 160 participants equally distributed between the groups. The participants were considered to have fulfilled the program if they attended 5 or more sessions. Based on previous studies in similar populations, we emphasized a 25% drop-out. The intervention was completed twice a year (spring and autumn) during the years of 2018 and 2019 which causes some variance as Finland is a northern country with dark, and commonly cold winters. The COVID-19 epidemic in 2020 hindered the group interventions reducing the total number of participants. A Nature-group was organized in autumn 2020, but its data is not included in this study due to the contrasting general circumstances. A separate qualitative follow-up study was conducted in 2022 (26).

It was possible to participate the intervention without being part of the study. Participants in the study signed an informed consent form allowing the use of data and giving permission to recontact. Participants were free to withdraw from the study at any time without giving a reason, and this did not interfere with their care in any way. The study was approved by the coordinating Ethical Committee of Helsinki and Uusimaa Hospital District (HUS/3520/2017) and study permission was granted by the municipality (7.2.2018). All data is anonymized and stored at the Finnish Institute for Health and Welfare (THL).

2.2. Methodology

Our main outcome is the self-assessed mental wellbeing. Secondarily, we also analyze self-reported and device-based sleep. A flow-chart of the assessments is displayed in Figure 1.

2.2.1. Questionnaire

Self-assessed mental wellbeing was measured with the 14-item Warwick-Edinburgh Mental Well-Being Scale (WEMWBS). The questionnaire also included demographic information (gender, age) and 6 additional questions (Q1–Q6) rated on a Likert-like scale: 1 (little/bad/badly) to 5 (much/good/well). Personal preference was measured in Q1 (*Is nature important to you?*) and Q2 (*Is physical exercise important to you?*). Perceived health and sleep were assessed in questions Q3 (*How is your health at the moment?*), Q4 (*How is your mental health at the moment*?), Q5 (*How is your ability to function at the moment*?), and Q6 (*How do you sleep at the moment*?). Answers were collected before beginning the study, at the fourth meeting, and at end of study. We report the answers from the beginning and the end. Questionnaires were in the native languages Finnish and Swedish. Demographic variables include age and gender. Information on the socioeconomic status, ethnic background, or time of residency in the area were not collected.

The WEMWB scale was developed to assess positive mental wellbeing (27, 28), and although it was not devised to diagnose mental illness, it has shown consistency with scales assessing depression and anxiety disorders (29, 30). The WEMWBS has been validated for use in primary care populations in Nordic countries (31). The WEMWBS measure is responsive to change on both individual and group level (29, 30).

2.2.2. Accelerometer measurements of sleep

Each participant was provided with a wrist worn accelerometer *(ActiGraph GT9X Link, Actigraph LLC, Pensacola, Florida, United States)* to assess their physical activity and sleep before starting the program and after the intervention. Participants were instructed to wear the accelerometer for at least three consecutive days, removing it only if taking a bath or having a sauna. Participants kept a diary of their sleep schedules while wearing the accelerometer. Accelerometer data were extracted and analyzed using Actilife 6 software (*Actigraph LLC, Pensacola, Florida, United States*). For the purposes of this study accelerometer-based sleep periods were analyzed using the Cole-Kripke sleep detection algorithm (32). Analyzed measures included: (1) total sleep time (minutes), (2) time in bed (minutes), (3) sleep efficiency (%), (4) the number of times the participants awoke having already fallen asleep, and (5) length (minutes) of wakefulness after sleep onset averaged over the measurement days.

2.2.3. Statistical analyses

We created groups for self-reported health outcomes, where scores of 1 to 3 were regarded as poor health and scores of 4 and 5 as good health. Data were tested for normality. The differences between the Nature-and Sports-groups as well as between the categorial groups were assessed using Student's *t*-tests for normally distributed variables and using Pearson's Chi-squared tests or Mann–Whitney *U*-tests for non-normally distributed variables as appropriate.

The changes in WEMWBS, Q1–Q6 scores and accelerometer data were analyzed using either dependent t-test or Wilcoxon signed-rank test, depending on the distribution of data. Answers of Q1–Q6, gender, age, group, and season were further used as covariates in univariate regression models analyzing factors which may explain the changes in the WEMWBS sleep outcomes. The statistical analyses were performed using IBM SPSS Statistics, version 27, software.

3. Results

A total of 79 participants are included in the study, their mean age was 57 years (range 29–81), and the participants were predominantly female (79%). The Nature-group was more popular, with 58% of the

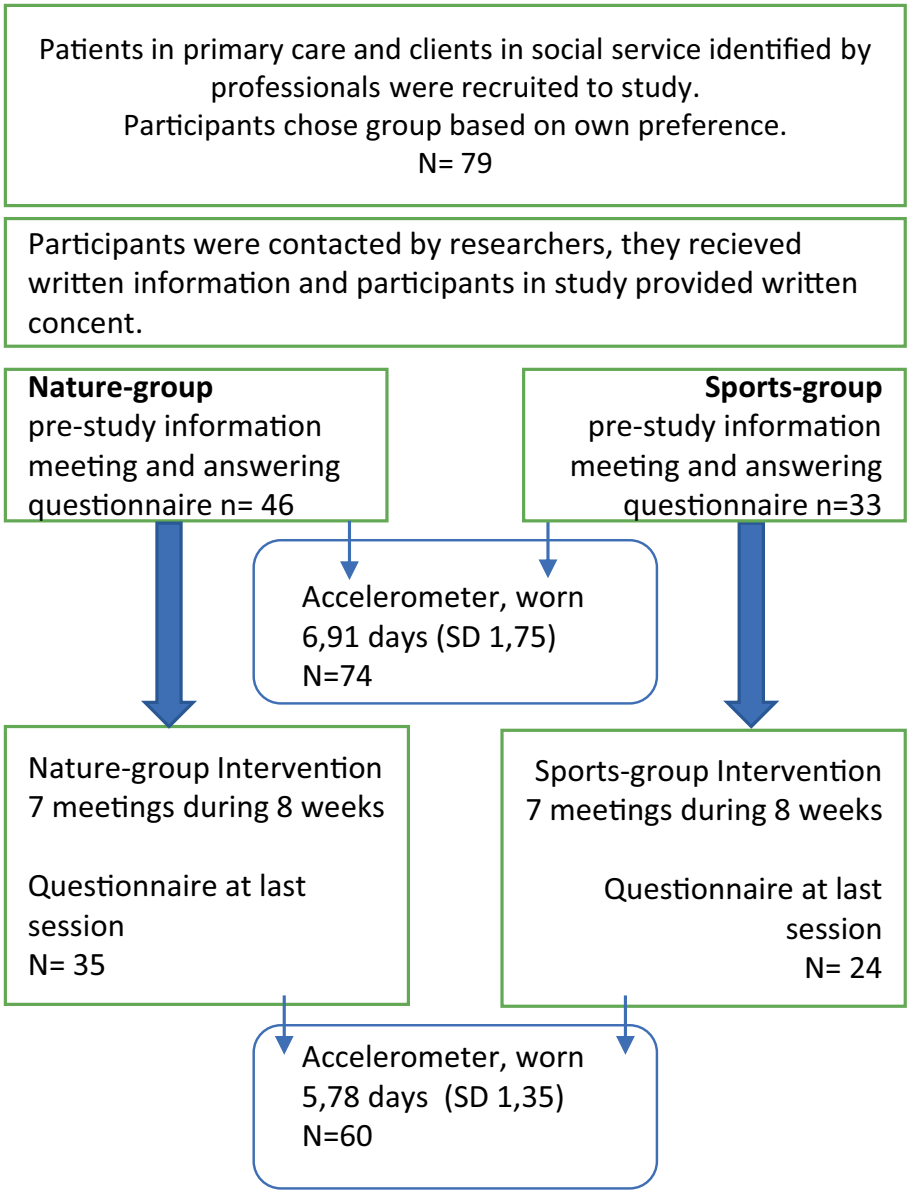

FIGURE 1
Flowchart of intervention.

participants. At the start of the study, the demographic characteristics, personal preferences for nature and exercise or perceived health did not differ between the groups. The spring and autumn groups are also comparable. Due to the small number of participating men, results are not grouped by gender. Of those starting the program, 72% attended 5 or more sessions and were considered fulfilling the program. Three of those signing up for the intervention did not attend any session and the pre-measurement data on two participants was missing. Included participants attended 5.3 sessions on average (SD 1.6). We tested the likelihood for dropping out of the intervention but found no probability depending on or either the self-rated health, mental health, physical ability, sleep, season, gender, or group.

The accelerometer was worn for 7 days on average (SD 1.76, range 2–9) before the intervention and for 6 days on average (SD 1.38, range 3–8) after the intervention. Descriptive statistics are presented in Table 1.

TABLE 1 Descriptive data at baseline.

		All	Naturegroup	Sportsgroup	*p*
Female n (%)		62 (79)	37 (80)	25 (76)	0.618
Season, attenders in spring		52 (66)	29 (63)	23 (70)	0.633
	n	M (SD)	M (SD)	M (SD)	
Age in years (Range 29-81)	73	57 (11)	58.2 (11)	55.6 (11.8)	0.171
Attendance, n (Range 1-7)	75	5,3 (1,6)	6 (1,8)	5 (2)	0.165
Accelerometer use			n	M (SD)	
Days used before intervention			74	6,91 (1,75)	
Days used after intervention			60	5,78 (1,35)	

p value indicates difference.

3.1. General health

At baseline, only 26% of the participants considered themselves in good general health on the 1-to-5 scale (mean 2.97, SD 0.93), 20% felt their physical ability was good (mean 2.77, SD 0.92) and 44% rated their mental health as good (mean 3.31, SD 0.94). Following the intervention, the perceived health improved (mean change 0.4, 95% CI 0.21 to 0.59, $p < 0.001$), the functional ability improved (mean change 0.45, 95% CI 0.28 to 0.62, $p < 0.001$), and the mental health improved (mean change 0.25, 95% CI 0.07 to 0.43, $p = 0.008$).

The descriptive data and the change in outcomes following the intervention are presented in Table 2. Before starting the study, 88% of all attenders found nature important or very important (mean 4.35, SD 0.7). Even though the perceived importance of nature was high, a further improvement (mean 0.17, 95% CI 0.04 to 0.29, $p = 0.012$) was observed in the Nature-group. Exercise was important to 58% of the participants, and at the end of the study, the importance of exercise had increased (mean change 0.28, 95% CI 0.12 to 0.44, $p < 0.001$).

3.2. Mental wellbeing

The change in mental wellbeing using the WEMWBS score was our primary outcome, we analyzed the impact participation in the interventions had on the whole group, as well as considering the Nature-group and Sports-group separately. The compared groups did

TABLE 2 Perceived health, mental wellbeing and sleep at baseline for all participants and mean change within groups after intervention Baseline information includes all participants, the groups did not differ at baseline.

Total, baseline			Nature-group			Sports-group		
Perceived health	N	M (SD)	N	Mean Change	*p*	N	Mean Change	*p*
How is your health at the moment? (1–5)	75	2.97 (0.93)	36	0.39 (0.16 to 0.62)	**0.002**	24	0.42 (0.09 to 0.74)	**0.01**
26,7% considered their health to be good[β]								
How is your mental health at the moment? (1–5)	75	3.31 (0.94)	36	0.39 (0.16 to 0.62)	**0.002**	24	0.04 (−0.25 to 0.33)	0.77
44% considered their mental health to be good [β]								
How is your physical ability at the moment? (1–5)	75	2.77 (0.92)	36	0.47 (0.22 to 0.72)	**<0.001**	24	0.42 (0.2 to 0.63)	**<0.001**
20% considered their physical ability to be good [β]								
Total WEMWBS score**	68	48.3 (7.9)	33	3.15 (0.87 to 5.43)	**0.008**	21	0.76 (−1.82 to 3.34)	0.545
Sleep				**M (SD)** z			**M (SD)** **z**	
How do you sleep at the moment? (1–5)	75	2.88 (1.14)	36	3.5(1) z= −3.78	**<0.001**[†]	24	3.3(1) z= −1.81	0.07[†]
31% felt they slept well [β]				**Mean Change**			**Mean Change**	
Total sleep time (h – min)	74	4.8 h (1.2)	35	−15.4 min (−35.35 to 4.54)	0.13	24	14.15 (−10.65 to 38.94)	0.25
Total time in bed (h – min)	74	5.4 h (1.3)	35	−18.35 min (−40.23 to 3.53)	0.1	24	14.95 (−12.91 to 42.82)	0.28
Sleep efficiency (%)	74	89 (4)	35	0 (−0.98 to 0.99)	0.99	24	0.03 (−1.21 to 1.28)	0.96
Wake after sleep onset (min)	74	34 (13)	35	−2.9 (−6.12 to 0.33)	0.08	24	0.81 (−4.6 to 6.2)	0.76
Number of awakenings after	74	14 (5)	35	−1.4 (−2.78 to −0.01)	**0.05**	24	0.95 (−1.07 to 2.98)	0.34
Average length of awakening (min)	73	2.58 (0.6)	35	0.04 (−0.13 to 0.21)	0.62	24	−0.17 (−0.48 to 0.14)	0.27
Importance of nature and exercise				**M (SD)** **z**			**M (SD)** **z**	
Is nature important to you? (1–5)	75	4.36 (0.69)	36	4.5(0.6) z = −2.12	**0.03**[†]	21	4.4(0.7) z= −1.41	0.16[†]
88% considered nature important [β]				**Mean Change**			**Mean Change**	
Is exercise important to you? (1–5)	75	3.77	36	0.22 (0.02 to 0.42)	**0.03**	24	0.38 (0.1 to 0.65)	**0.01**
58.7% considered exercise important [β]								
Change		**M (SD)**		**M (SD)**			**M (SD)**	
Change in total WEMWBS score**	54	2.2 (6.2)	33	3.2 (6.4)		21	0.8 (5.7)	0.17[‡]

[β] (score 4-5) *T-test and [†] Wilcoxon (difference within groups) [‡] independent T test (difference between groups).
**Warwick-Edinburgh Mental Well-Being. Bold values indicates statistical significance.

not differ at baseline, both groups were normally distributed although at endpoint the range was bigger in the Nature-group (Table 2). The participants fulfilling the interventions ($n = 54$) showed a significant improvement in the total WEMWBS score with a mean change of 2.2 points ($p = 0.01$). However, the change observed in the whole group is mainly due to the good effect of the Nature-group ($n = 33$), where a mean change of 3.5 points ($p = 0.008$) was observed, compared to a mean change of 0.4 point ($p = 0.75$) in the Sports-group ($n = 21$). For the Nature-group, participation in the intervention improved: the feeling of being relaxed, the feeling of having energy to spare, feeling of dealing well with problems, feeling good about oneself, feeling of being close to other people, and feeling of being cheerful. The WEMWBS results are displayed in Table 3. Neither age, gender nor season influenced the change in mental wellbeing. In the univariate models, perceived general health ($p = 0.005$), physical ability ($p = 0.006$) and mental health ($p = 0.012$) all statistically predicted WEMWBS change, whereas self-rated sleep did not.

3.3. Differences in mental wellbeing by general and mental health status

An important finding is that the participants with poor perceived health had less improvement, or even a reduction, in mental wellbeing compared to those considering their health good. Results are presented in Figure 2. In the Nature-group, participants in poor perceived health ($n = 26$) showed an improvement in the WEMWBS scores, the mean change was 3.12 (95% CI 0.77 to 5.46). If health was rated good ($n = 7$), the mean change was 3.29 (95% CI −4.98 to 11.55), the difference depending on the self-rated health status is non-significant ($p = 0.95$). However, in the Sports-group, those in poor health ($n = 15$) showed reduced mental wellbeing, their mean WEMWBS change was-0.93 (95% CI −4.10 to 2.24), whereas those in good health ($n = 6$) had the best response to the intervention, their mean change being 5 (95% CI 2.26 to 7.74), the difference depending on the self-rated health status is significant ($p = 0.004$).

The pattern is similar regarding perceived mental health, and here, there was a difference depending on perceived health in both groups. In the Nature-group, those in poor mental health ($n = 20$) had a mean change of 1.15 (95% CI −1.23 to 3.53) in their WEMWBS scores, but those initially rating their mental health as good ($n = 13$) improved more (mean 6.23, 95% CI 1.87 to 10.6, $p = 0.039$). In the Sports-group, we observed a reduction in WEMWBS scores for participants initially rating their mental health as low ($n = 12$). Their mean change was-1.17 (95% CI −1.99 to 2.65), and if initial self-rated mental health was good ($n = 9$), the WEMWBS scores improved (mean 3.33, 95% CI 0.09 to 6.57, $p = 0.071$).

3.4. Sleep

Sleep quality and sleep duration was generally low in this population, only 31% felt they slept well. Mean time in bed assessed by accelerometers was only 5.4 h (SD 1.3) and mean sleep time 4.8 h (SD 1.2). 81% slept less than 6 h per night, usually considered as an

TABLE 3 Change in positive mental wellbeing.

		All participants n = 59–60			Nature-group N = 34–35		Sports-group N = 23–24	
Question score 1–5		Mean (SD)	Mean change (95% CI)	p	Mean change (95% CI)	p	Mean change (95% CI)	p
1	I've been feeling optimistic about the future	3.5 (0.8)	0.14 (−0.05–0.33)	0.159	0.23 (−0.02–0.48)	0.073	0 (−0.31–0.31)	1
2	I've been feeling useful	3.5 (0.8)	0.07 (−0.13–0.26)	0.497	0.08 (−0.16–0.33)	0.499	0.04 (−0.3–0.38)	0.802
3	I've been feeling relaxed	3.1 (0.8)	**0.27 (0.06–0.49)**	**0.015**	**0.31 (0.02–0.6)**	**0.039**	0.22 (−0.13–0.56)	0.203
4	I've been feeling interested in other people	3.7 (0.8)	0.13 (−0.07–0.34)	0.197	0.14 (−0.08–0.36)	0.201	0.13 (−0.29–0.54)	0.543
5	I've had energy to spare	3 (0.8)	**0.35 (0.13–0.57)**	**0.002**	**0.42 (0.11–0.72)**	**0.009**	0.25 (−0.06–0.56)	0.11
6	I've been dealing with problems well	3.2 (0.8)	0.18 (−0.04–0.41)	0.109	**0.31 (0.02–0.6)**	**0.039**	0 (−0.37–0.37)	1
7	I've been thinking clearly	3.6 (0.7)	−0.07 (−0.27–0.13)	0.497	0.06 (−0.18–0.29)	0.624	−0.25 (−0.61–0.11)	0.162
8	I've been feeling good about myself	3.2 (0.7)	0.14 (−0.05–0.33)	0.159	**0.31 (0.07–0.55)**	**0.014**	−0.13 (−0.43–0.17)	0.377
9	I've been feeling close to other people	3.4 (1)	0.3 (0.05–0.55)	0.019	**0.39 (0.08–0.69)**	**0.014**	0.17 (−0.28–0.61)	0.445
10	I've been feeling confident	3.4 (0.9)	0.1 (−0.12–0.32)	0.359	0.26 (−0.02–0.54)	0.071	−0.13 (−0.48–0.23)	0.479
11	I've been able to make up my own mind about things	4 (0.8)	0.02 (−0.14–0.17)	0.829	0.03 (−0.19–0.25)	0.8	0 (−0.23–0.23)	1
12	I've been feeling loved	3.6 (1)	0.07 (−0.12–0.26)	0.484	0.19 (−0.06–0.45)	0.128	−0.13 (−0.43–0.17)	0.377
13	I've been interested in new things	3.8 (0.8)	0.17 (−0.02–0.36)	0.077	0.22 (−0.05–0.49)	0.103	0.09 (−0.17–0.34)	0.492
14	I've been feeling cheerful	3.6 (0.8)	0.19 (−0.03–0.4)	0.086	**0.39 (0.08–0.69)**	**0.014**	−0.13 (−0.37–0.11)	0.266
	Total WEMWBS score	48.3 (7.9)	**2.22 (0.53–3.92)**	**0.011**	**3.15 (0.87–5.43)**	**0.008**	0.76 (−1.82–3.34)	0.545

Measured on the Warwick-Edinburgh Mental Well-Being Scale (WEMWBS). Bold values indicates statistical significance.

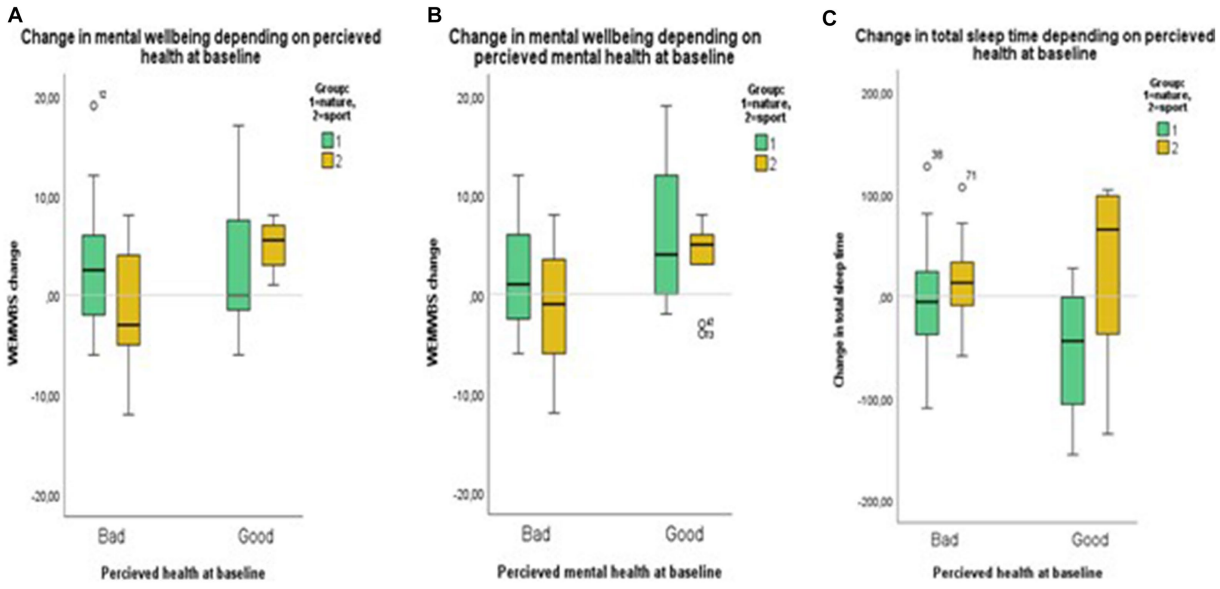

FIGURE 2
Illustrates change in WEMWBS score depending on **(A)** self-rated health, and **(B)** mental health, as well as **(C)** change in sleep time depending on self-rated health at baseline.

insufficient amount of sleep. Accelerometer-based number of awakenings (NOFA) after sleep onset was 14 on average (SD 5) and mean time wake after sleep onset (WASO) was 34 min (SD 13). Sleep efficiency (SE) was 89% on average.

Following the intervention, 61% (22 out of 36) of the participants in the Nature-group experienced a positive change in perceived sleep ($z = -3.78$, $p < 0.001$). In the Sports-group, 33% (8 out of 24) reported improved sleep quality ($z = -1.81$, $p = 0.07$). This is contradictory to the observed accelerometer measures, where total sleep time reduced (−15 min) in the Nature-group but increased (+14 min) in the Sports-group. The difference between the groups was near a statistical significance ($p = 0.06$; see Table 2). In the Nature-group, change in total sleep time depended on perceived health. The mean change in sleep time was −48 min (SD 64 min) if health was good ($n = 9$), but-4 min (SD 52 min) if health was rated poor at baseline ($n = 26$). Independent *t*-test indicated a difference between the groups ($p = 0.047$). This pattern was not seen in the Sports-group (Figure 2). In the Nature-group, NOFA decreased by 1.4 on average (95% CI 2.8 to zero, $p = 0.05$) and WASO decreased with 2.9 min on average (−6.1 to 0.3 min, $p = 0.08$), whereas no change occurred in the Sports-group. Sleep efficiency did not change in either group.

4. Discussion

First, we address the third aim of this study, i.e., investigating the impacts of health status on the effects of the social prescribing interventions. Next, we discuss about implementation of the interventions, and finally, we discuss on the strengths and limitations of this study.

As intended, participants in the study rated their health lower than the general population. Only 27% regarded their health as good or very good, with the corresponding figures being 62% for men and 63% for women responding to the Finnish population survey FinHealth 2017 (33). Although diagnoses are not reported, we know that multimorbidity is established in the sample. Poor self-rated health is associated with frequent attendance in primary care (34). Health professionals seemed to have a good ability to select those patients suitable for social prescribing programs.

4.1. Mental wellbeing

The WEMWBS average of 48 is inferior to that of the general population. In the FinHealth 2017 survey, the average WEMWBS score in southern Finland was 52.8 (95% CI 52.3 to 53.3) (35). Although WEMWBS is not a diagnostic tool, persons with a total score of ≤40 ought to be considered to have a high risk of major depression, while scores between 41 and 45 indicate a high risk of psychological distress and increased risk of depression (17, 28). Several of the participants in this study might have suffered from common mental health disorders, but we lack information on diagnosis or treatment. Most participants in poor health were able to complete the program.

Improved mental health is associated with reduced mortality and mental illness (16), better physical health, social functioning, as well as academic achievement (17, 36). Using the 7-item SWEMWBS scale and applying the English population norms for it, a change of 1 to 3 points may be taken to denote a change that is statistically meaningful (29, 30), therefore the improvement of 3.5 points in the Nature-group observed in our study may be considered as clinically significant. It is of note, however, that we used the 14-item WEMWBS. In the Nature-group, positive changes were observed for the score of feeling able to deal well with problems, feeling good

about oneself, and the feeling of being cheerful. This suggests an increase in mental resilience as an effect of nature-based social prescribing and is a significant finding. In the Sports-group, the improvement in mental wellbeing perceived by participants who rated their health as good is also evident, while the slight reduction observed when health was poor is rather not a change. A more pronounced gain in wellbeing for those with better self-rated mental health is common in health interventions. The WEMWBS improvement observed in the Nature-group when perceived health or mental health was poor supports the yet tentative evidence that nature-based social prescribing schemes could be preferrable particularly for persons suffering from mental health disorders (12).

Social interaction and reduced loneliness are potential mediators for well-being (7, 37). Loneliness, a state associated with several adverse health outcomes, is common in all age groups (38, 39). In the Nature-group there was an increase in feeling close to other people. Nature has had a positive effect in empowering groups in previous studies (7, 8). However, some qualitative studies have indicated that people suffering from common mental disorder might react negatively to social pressure, even though the likelihood of visiting green space increased, if experiencing social pressure, the intrinsic motivation and visit happiness might decrease (40). Understanding the underlying cause for individual variance is of importance in future research, perceived mental health might be diminished due to several reasons, i.e., mental disorder or loneliness. In our study, social interaction was planned to be comparable in the groups and both programs aimed to improve social cohesion, thereby equalizing the effect of reduction in loneliness. However, the quality of the social interactions may have differed between the groups, and our results suggest that nature surroundings have played a part in increasing social cohesion and decreasing the experience of loneliness as found in earlier research (41).

4.2. Sleep

Poor sleep surfaced as a clear finding, 81% slept less than 6 h per night and 70% of the participants also rated their sleep quality as poor. In the FinHealth 2017 study, the average self-reported sleep time was 7.4 h for adults aged over 30 years, with only 14% of the women and 16% of the men sleeping less than 6 h per night. Following the intervention, total sleep time improved in the Sports-group but decreased in the Nature-group. This change was close to significant and opposite to our expectation. Diminished sleep time was observed only in the participants with good self-rated health. Despite this accelerometer-based outcome, perceived sleep improved significantly in the Nature-group, with reduced time awake after sleep onset and reduced number of awakenings being likely explanations for the positive experience.

Population studies have indicated that surrounding greenery has a positive impact on sleep duration (42), but only a few intervention studies have addressed the issue, with weak study designs (43). Our findings underline the importance of assessing sleep as a part of general wellbeing, and they also show the complexity of insomnia. Time asleep does not always correlate with perceptions of sleep, and stress reduction can partly explain the positive outcomes encountered. Previous studies suggest that residential greenness improves sleep by reducing stress caused by air and noise pollution (42).

4.3. Nature connectedness as a potential pathway to positive mental wellbeing

Even though most of the study participants rated nature as very important at baseline, taking part in the Nature-group further strengthened this feeling. Experiencing interconnection with nature increases the motivation to protect and defend it, and the improved connection with nature also increases happiness and wellbeing (44), while reducing anxiety (45). Anxiety and symptoms of depression were not assessed in our study, but previous research indicates nature-based interventions can reduce these symptoms in populations with or without pre-existing mental health problems (12), a strengthened connection with nature is a potential explanation. The Nature-group intervention included activities aiming for increased nature connectedness, as previous research emphasizes the quality of contact with nature rather than mere time outdoors (46).

Contact with nature appears to be important to human health, since living close to green space has an inverse association with all-cause mortality, especially mortality due to cardiovascular disease (2, 4, 47). In addition, contact with nature is known to diversify human microbiome on the skin and in the gut, triggering a healthy immune response (48, 49). The pathways through which exposure to nature influences health are many and interlinked. A widely adopted explanative framework summarizes these pathways by dividing them into those that (a) reduce harmful exposure (air pollution and noise), (b) enhance healthy behavior, and (c) activate human restorative capacities (50). It is likely that these pathways play different roles at different stages through life. Outcomes are also dependent on the way in which we interact in and with our natural surroundings (3).

The restorative capacity of nature is commonly explained by (a) the stress recovery theory, which underlines that contact with nature promotes a positively toned mental state and activates the parasympathetic nervous system (51), or/and (b) the attention restoration theory, emphasizing that nature can restore the ability to direct attention (52). Stress recovery is not only a feeling, but exposure to nature has also repeatedly been demonstrated to reduce physiological stress responses (51, 53). Both healthy and vulnerable populations have shown improved cognitive function during and after outdoor interventions (7, 53, 54). Over time, lack of restoration can lead to mental and physical illness (55).

High perceived stress increases reliance on primary care service (56). Unspecific symptoms secondary to stress, such as anxiety, insomnia or physical symptoms are common reasons to make contact with primary care services (57). In our study, the score for feeling relaxed improved among all participants and significantly in the Nature-group.

There is a knowledge gap regarding what role contact with nature has on an individual level, as personal preferences and cultural values influence how we experience nature and how willing we are to interconnect with it (3). The personal psychological connection with nature is referred to as nature connectedness. Health outcomes vary depending on how we feel in the natural environment (58) and, interestingly, perceived biodiversity can have stronger correlations with well-being than actual biodiversity (48). In national surveys, Finns repeatedly report that they appreciate nature and greenness, and although 72% of Finns live in urban areas, the average distance to a forest is only 700 m (59). Public access rights in Finland allow people to move, pick berries and mushrooms and spend time on public as

well as private land, as long as one keeps out of cultivated farmland and private gardens. People living in Finland usually have high nature connectedness and enjoy outdoor activities (59).

4.4. Can nature-based social prescribing reduce inequality?

In a global context, Finns are healthy (60). The life expectancy in Finland is among the highest in the world, and Finland has ranked first in global life satisfaction reports, i.e., World Happiness Reports (61). However, health inequity is a big concern, as it is recognized that those who are wealthier are healthier, more physically active and have better access to care than those with lower socioeconomic status (60), even though the Finnish health services are publicly funded and affordable. One concern is that people with risk factors such as sedentary living, obesity, loneliness, or mental disorders do not actively seek help, and are therefore not included in preventive programs. The Finnish Institute for Health and Welfare has estimated that reducing inequalities could reduce direct health-based costs by 1.5 to 2.0 billion euros, where indirect costs due to reduced ability to work are not included in this estimate (62, 63). Gender difference in life expectancy as well as socioeconomic inequality is a well-documented challenge to be solved (62, 64), as women are generally more interested in health-related information and eager to participate in interventions (64). This study was not an exception, the shortage of male participants was a disappointment, we had emphasized that the Nature-group would appeal to men. Hopefully, this will change as we gain more evidence on the effects of nature-based interventions. As a follow-up to the current study, participants of the Nature-group 2018–2020 were contacted during 2022, and 23 of them took part in qualitative interviews reported by Heikkinen (26). Several participants mentioned that they would not have taken part in the intervention had they not been referred by health professionals, and initially thought it was an odd suggestion. Afterwards they found it as a novel and positive part of public health services. The support from the peers and the leaders was also considered very important. Participants also felt they had either established or regained contact with the natural environment and brought up the observation that they had forgotten how meaningful nature is as a source of wellbeing. These themes are in line with theoretical guidance conceptualizing how to best implement nature-based interventions (8).

Primary care patients seek help for various symptoms that may or may not be caused by a disease. General practitioners (GPs) are at the frontline in diagnosing medical conditions, but also familiar with the role that social and psychological factors play in wellbeing. One example is a recent Swedish cross-sectional study of a middle-aged general population concluding that angina pectoris symptoms, irrespective of degree of coronary atherosclerosis, are highly associated with stress and depressive symptoms, among other sociodemographic and psychological factors (65). Approaches for a more holistic health care system are needed. Social prescribing—also called community referral—is an emerging method that enables GPs, nurses, and other healthcare professionals to refer patients in need of support to a range of local, non-clinical services (10, 11). Nature-based social prescribing is a potential way of reducing pressure on health and social service, and although the cost-benefits of social prescribing are yet to be determined, cost savings have been reported when the target group has been frequent attenders (66). Understanding the needs and wishes of those participating in health interventions is crucial in improving motivation and succeeding in behavioral change. In this study, participants in the Nature-group showed improvement in feeling good about oneself, having energy to spare and dealing with problems well, all these qualities being important in order to succeed in change and when coping with chronic disease. Non-pharmaceutical health promotion is an important part of general practice, it is a potential way to prevent illness at an early stage, therefore it is an effective and cost-effective treatment. Although preventative programs are widely used in Finland, they are commonly targeting patients with a specific diagnosis. The concept of social prescribing aiming for a broad improvement in general health and positive mental wellbeing is new in Finland (67).

4.5. Strengths and limitations

This is a non-randomized pilot study in a real life, primary care setting and should be interpretated as such. Some aspects can be regarded both as strengths and limitations. First, inclusion was not based on a specific disease or diagnosis, but a common need for general health improvement. This strategic choice is based on the knowledge that primary care patients seek help for various health problems and symptoms, and frequent attenders commonly suffer from symptoms that might not be due to a specific diagnosis (15, 57). Participants referred by social workers may or may not suffer from medical conditions. By choosing an approach aiming to improve health without addressing a medical problem, we lost an opportunity to examine how nature can be used as a treatment for a specific disease. Studies which use diagnoses as outcomes require large population-based samples and long follow-up periods (2) that is beyond the scope of this study. Poor self-rated health is a risk factor for long-term frequent use of primary care (15), but it is unknown to what extent improved perceived health influences the use of health services.

Second, some methodological limitations need to be noted. All participants live in an area with abundant green and blue spaces, therefore, it is likely that the participants in the Sports-group also spent active time outdoors. Sleep was assessed by wrist-worn accelerometers that are considered acceptable for use in population studies or community-based interventions, and they compare rather well with polysomnography, which is considered the gold standard measure of sleep (68). However, there are still weaknesses with accelerometers. They have a low specificity for detecting when one is truly awake (69). The detection of sleep and wake is based on an algorithm which may falsely identify times such as non-wear or motionless periods as sleep, lowering the specificity. Also, it should be noted that if the participants slept during the day, also these periods were included in the averaged sleep data. However, the collected accelerometer data is in line with the self-reported sleep quality measures. To keep the questionnaire simple and to ensure that the participants completed the questionnaire, we preferred single-item questions to multi-item scales for the assessment of nature connectedness and sleep. As 78% of the participants were female, conclusions on the influence of gender cannot be drawn from the

study. No adverse events or accidents were reported in either group, but we did not have a structured protocol for collecting information about adverse effects.

Third, the follow-up time is short. The social restrictions following the outbreak of the COVID-19 pandemic ended this study early, therefore, we were able to recruit approximately half of the planned number of participants. A six-month follow-up questionnaire was initially planned, but as the COVID-19 pandemic occupied professionals, it simply was not possible to fulfill this part of the study. Also, we were not able to analyze how participation in the intervention affected the use of health care services. Research in primary care faces pragmatic challenges and needs stronger structure in Finland. Digital tools could facilitate communication between participants and instructors as well as providing a platform for follow-up when developing social prescribing programs. However, consideration of the target groups' ability to use technical devices is important. The national Sustainable Growth Program in Finland is part of the NextGenerationEU program, aiming to support growth that is ecologically, socially and economically sustainable (70). The Finnish Institute for Health and Welfare is developing models for future healthcare in which social prescribing is included (71). National coordinating is necessary especially in the assessment of the effects of interventions, while field studies like ours provide influential information on the feasibility of the interventions.

Fourth, this was not a randomized controlled trial. The concept of Health Forest started out as a trial, and the study protocol evolved from these experiences. As the project had gained public interest before the study, positive perception may impact the results in favor of the Nature-group, also among the referring health professionals. Even so, the activities for the Sports-group were planned carefully to represent the current best practice. Primary care clients committed to both social prescribing schemes, and no adverse effects nor adverse events occurred. We found no difference in season, and this being found the Nature-groups can be organized all year round also in Nordic countries. Based on the encouraging results we hope to see more preventive projects utilizing nature and research addressing how nature can be used as a treatment. In future research, the use of cluster randomization is a way to provide a more robust study design. In bigger studies, inclusion of health data such as diagnosis and medication could help us understand more about the conditions to which nature-based social prescribing is best of help, and by including information health metrics we might also learn whether nature-based interventions can reduce demand on health and social service.

The programs used in this study can be adapted to different target groups and locations, and we consider the practical approach as the biggest strength of this field-study.

5. Conclusion

Our results support the increasing understanding that nature-based interventions have a positive effect on mental wellbeing in primary care patients. In green surroundings, prescribed nature-based interventions or group exercise can improve perceived health and ability to function. Improved mental health and positive mental wellbeing was observed only in the Nature-group. Based on the observed differences in improved mental wellbeing depending on perceived health, we would recommend either sports or nature-activity for those initially feeling healthy, and nature-based intervention especially for those rating their health as poor.

Data availability statement

The datasets presented in this article are not readily available because according to the research permission all data is anonymised and stored at the Finnish Institute for Health and Welfare. Data can be shared with a specific request from the institute, but not be shared by the researchers. Requests to access the datasets should be directed to research professor TP, timo.partonen@thl.fi.

Ethics statement

The studies involving human participants were reviewed and approved by Ethical Committee of Helsinki and Uusimaa Hospital District (HUS/3520/2017) and study permission was granted by the municipality of Sipoo (7.2.2018). The patients/participants provided their written informed consent to participate in this study. This study was registered as a clinical trial (ClinicalTrials.gov, Identifier NCT05893212).

Author contributions

TP, MH, AP, and AM: conceptualization, methodology, and planning. AK, TP, AP, and HW: literature review. HW: preparation of accelerometer data. AK and TP: statistical analysis. AK: writing—original draft preparation. AK, TP, MH, and AP: writing—review and editing. TP: supervision and owner of data. All authors contributed to the article and approved the submitted version.

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Conflict of interest

AP was an entrepreneur at Luonnontie, a company developing Health Forest models.

The remaining authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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.2023.1208858/full#supplementary-material

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Cloudy or sunny? Effects of different environmental types of urban green spaces on public physiological and psychological health under two weather conditions

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Numerous studies have demonstrated that urban green spaces (UGSs) benefit human health, but few have focused on the influence of weather on environmental restorativeness. This study assessed how different weather conditions and environments affect human health. We exposed 50 participants to different UGS environments under cloudy and sunny conditions and collected physiological, psychological and aesthetic preference data. The result showed that the physical and mental benefits of UGSs were stronger on sunny days (pulse: [$t = 2.169$, $p < 0.05$]; positive affect: [$Z = -10.299$, $p < 0.001$]; perceived restortiveness: [$Z = -3.224$, $p < 0.01$]). The spaces with exposed sky had greater physiological restorativeness on sunny days; the spaces with calm water had greater emotional restorativeness on cloudy days, and natural spaces with less sky exposure had greater perceived restoration in both weather conditions. The spaces with water and less sky exposure promoted psychophysiological restoration in both weather conditions. This study demonstrates that weather significantly influences the restorative potential of UGSs, and there are also restorative variations in different green space environments under two weather conditions. In future UGS planning practices, it would be advisable to select appropriate environmental types and features based on the climatic characteristics of different regions. For instance, in areas with frequent overcast conditions, incorporating serene water bodies could be advantageous, while regions with predominantly sunny weather should encompass spaces with expansive sky views. By conducting comprehensive research on restoration environments that take weather conditions into account, new insights and nature-based solutions can be provided for creating healthy human habitats in the context of global climate change.

KEYWORDS

restorative environments, urban green spaces, weather conditions, environment types, environmental health

1. Introduction

With rapid and intense urbanization around the world, the resulting high-density urban environments and high pressures of urban life have impacted people's physical and mental health (1). Research has demonstrated that urban green spaces (UGSs) play an important role in human health recovery and maintenance of well-being, serving as a nature-based solution (NBS) to improve health (2, 3). In addition, weather conditions directly affect people's perception of the environment (4) and the recovery effects of health (5). In daily life, the green space environment and weather conditions are experienced simultaneously. Interestingly, research on the individual effects of these two elements on health restoration is relatively in depth, but few studies have focused on the joint effects of the UGS environment types and weather conditions on human health. Therefore, we explored the joint effects of weather conditions and UGS environment types on physical and mental restoration to provide novel insights.

There are two prominent theories on how green space environments exert physiological and psychological restoration effects on humans: attention restoration theory (ART) and stress reduction theory (SRT). ART assumes that natural restorativeness is mainly due to the restoration of directed attention (6). In contrast, SRT emphasizes the release and reduction of stress in the environment and emphasizes emotional and physiological recovery (7). Moreover, related studies have also demonstrated that there is a positive correlation between aesthetic preference and health restoration (8–10).

Based on ART and SRT, numerous studies have indicated that green environments contribute to mitigating health deficits among residents, encompassing both psychological and physiological health restoration. Psychological health impacts involve the augmentation of positive emotions (11), reducing anxiety and stress (12), and improving perceived ability (13). Physiological health restoration encompasses the reduction of physiological parameters such as blood pressure, pulse rate, and salivary cortisol levels (14, 15), along with a decrease in the incidence and mortality rates of cardiovascular and respiratory diseases (16).

In terms of environmental characteristics, plants and water are important predictors of UGS restorativeness and preference (14, 17, 18). Even trees lacking leaves (i.e., in winter) can have positive effects on humans (19). Water bodies with good water quality and a natural form may be attractive and have restoration potential (20). Shi et al., (21) found that people prefer open spaces. In environments with rich vegetation and exposed sky, people tend to experience greater relief from depression and anxiety (22), greater perceived restoration (23) and greater physiological resilience (24); personal restoration is positively correlated with sky visibility (25). However, some scholars believe that lower sky visibility in autumn in Tokyo may improve the recovery of older individuals due to relief from heat stress and increase the vision greenery (26).

Numerous studies have demonstrated that sunny weather and good daylight could improve mood (23, 27), relieve stress (28), improve perception (29) and promote physical and mental health (30). Ulrich (31) found that daylight can affect people's environmental preference, thereby affecting restorativeness. In contrast, severe weather affects people's environmental preferences (32) and recovery potential (33). Research has investigated why sunny days facilitate recovery, and an in-depth physiological mechanism has been proposed. Specifically, with sunlight, ultraviolet A radiation releases nitric oxide stored in the dermis into the blood plasma, thereby dilating coronary arteries and exerting cardioprotective and antihypertensive effects (34–37).

Weather conditions have a greater impact on natural environment preferences than on artificial environment preferences (4), and severe weather has a greater impact on the restorativeness of water bodies (38). Natural environments with more green elements, more blue sky, and more sun exposure exert greater stress relief (22). Research has shown that changes in environmental quality and climatic conditions may increase attention, reduce the attractiveness of the environment, and reduce perceived compatibility and extent when visiting UGSs (39). However, regardless of the environment features, people prefer sunny days over cloudy days (40).

Although a small number of studies have focused on the impact of weather and environmental features on individual health recovery, there is still a lack of research on the restoration benefits of specific UGS environment features from a weather perspective. Therefore, we conducted comparative experiments in UGSs under both sunny and cloudy weather conditions. The physiological and psychological data of participants were measured before and after exposure to varying environmental types. Subsequently, we performed corresponding statistical analyses with the aim of addressing the following research questions: (1) Do the physiological and psychological restorativeness of UGSs remain consistent under cloudy weather conditions compared to sunny weather conditions? (2) Do different types of UGS environments have varying effects on physiological and psychological health under the two weather conditions?

2. Materials and methods

2.1. Participants

A total of 50 participants, evenly divided between males and females, were recruited for this study to control the potential confounding factors and biases arising from gender imbalance. According to the Central Limit Theorem, when the sample size exceeds 30, the sampling distribution of the mean tends to approach a normal distribution, satisfying the requirements for subsequent statistical analyses. Posters were posted within the university campus and its vicinity, and volunteers were also recruited through mobile group chat applications (WeChat) to expand the sample scope. Participants were selected then based on the following criteria: (1) self-reported normal vision and hearing, and (2) no history of cardiovascular or mental disorders. Participants were instructed to refrain from smoking, alcohol consumption, and vigorous physical activities before participating in the study. All potential participants were informed of the experimental procedures, associated risks, and provided informed consent before the commencement of the experiment. This study was approved by the Ethics Committee of the College of Landscape Architecture, Sichuan Agricultural University, China.

2.2. Study area, weather and sites

The study area was in Chengdu, Sichuan Province, China, which has a subtropical monsoon climate. Chengdu is located in the Sichuan Basin in the east of the Qinghai-Tibet Plateau, one of the four major basins in China. Due to the closed terrain, water vapour does not spread easily, and there are many cloudy days. The average number of annual sunshine hours in 2020 was 927.4 h, the lowest in China (41). Torshavn in the Faroe Islands, which is one of the cloudiest cities in the world, has an average annual sunshine time of only 1002.1 h (42). Thus, Chengdu is relatively representative of cloudy areas in the world.

To avoid the influence of confounding variables such as temperature, humidity, and wind speed due to the long interval between each experiment date, the experiments were conducted in autumn (November) when the cloud cover changes obviously on sunny and cloudy days and the climate is mild and pleasant for local residents (average temperature = 10–17°C). According to the American Meteorological Association, cloud cover is defined as the portion of the sky covered by clouds; on cloudy days, cloud cover is higher than 70%, and on sunny days, cloud cover is less than 20% (43). Two fully overcast days and two cloudless days were selected for the experiment based on the cloud cover reported by the China Meteorological Administration. To ensure that the temperature, humidity, and wind speed of each experiment were similar, the span of the experiment dates did not exceed 2 weeks. Objective climate data were also measured on the days of the experiment to reduce errors (Table 1). Before the experiment, the participants were informed of the temperature during the experiment and recommended to wear appropriate clothing (long-sleeved shirt and light jacket) to ensure thermal comfort.

The experimental site was Wenjiang Park in Wenjiang District, Chengdu. This park is the largest and most visited park in the area. Based on previous studies on environment characteristics, we extracted three characteristic dimensions of UGSs closely related to weather conditions and health: naturalness, water body, and the sky view factor (SVF, the fraction of visible sky in a specific place). Previous studies have shown that weather has a greater impact on the restorativeness of natural environment than on the restorativeness of artificial environments (4, 40), that environment restorative potential of bodies of water are highly influenced by weather (38), and that the SVF directly affects people's perceptions of weather conditions and the restorativeness of the environment (24). Three environmental characteristic dimensions were then classified: naturalness (high vs. low), body of water (presence vs. absence), and SVF (high vs. low). Naturalness was assessed by taking panoramic photos of eight experimental spaces from the participant's view and then calculating the coverage density of natural components (plants, water, and topography) and artificial components (landscape constructions, roads and pavement, and garden facilities) in each photo (44, 45). When the density of natural components in a space was higher than that of artificial components, the space was considered to have high naturalness; otherwise, it was considered to have low naturalness. The SVF was evaluated by photographing the sky using a fish-eye camera lens (Nikon D750 digital camera; Nikon AF DX Fisheye-NIKKOR 10.5 mm f/2.8G ED) at human height (46). When the proportion of visible sky was higher than 50%, the SVF was considered high; otherwise, it was considered low. The body of water was evaluated by the presence or absence of water in the sight range inside and around the experimental spot. After combining the 3 environmental features, 8 environmental types were generated. The corresponding 8 spaces in Wenjiang Park were selected for experiments after the field investigation (Figure 1). See supplementary material (Supplementary Figure S1) for the specific environmental information of the 8 spaces.

2.3. Procedure

The 50 participants were randomly divided into two groups, and each group was tested on a cloudy day and a sunny day, and the two experiments were separated by a week to eliminate legacy effects. The experiment was completed over a total of 4 days and within 2 weeks. Each day's experiment involved 25 participants, who were divided into 5 groups of 5. Experiments were conducted at the same times (10:00–12:00 and 13:30–15:30) each day to eliminate the influence of diurnal changes in physiological rhythms. Each group started the experiment at a different space and switched spaces in sequence to eliminate order effects. To eliminate fatigue, each group visited 4 spaces in the morning and visited the other 4 spaces in the afternoon. To eliminate legacy effects, the participants closed their eyes and rested for 3 min after each switch of space (before starting a new experiment).

The participants were first guided to the designated site by the researchers, who introduced the experimental process. After arriving at the experimental site, the participants closed their eyes and sat for 3 min to achieve a state of calm (47). After reaching a calm state, they were exposed to a stressful video for 1 min. The experimenters closely monitored the participants' emotional states throughout and ensured their right to withdraw from the stress video at any time (In the four-day experiment, only one female participant raised an issue regarding the slightly high volume of the stress video; subsequently, we lowered the volume and completed the entire experiment). Simultaneously, a counselor was available throughout the experiment to provide potential psychological support as needed, to ensure the well-being of the participants. Participants then took physiological

TABLE 1 Climatic data during the experiment.

	Weather	Temperature (°C)	Relative humidity (%)	Wind speed (m/s)
Day 1 (September 3, 2021)	Cloudy	14.3 ± 1.6	75.8 ± 6.2	1.1 ± 0.4
Day 2 (September 4, 2021)	Cloudy	14.8 ± 2.1	71.8 ± 3.6	1.3 ± 0.5
Day 3 (September 9, 2021)	Sunny	13.7 ± 1.7	54.4 ± 6.1	1.4 ± 0.5
Day 4 (September 12, 2021)	Sunny	14.2 ± 1.9	62.4 ± 11.8	1.4 ± 0.7

Values shown are the mean ± SD.

FIGURE 1
Descriptions and photograph of the 8 study spaces.

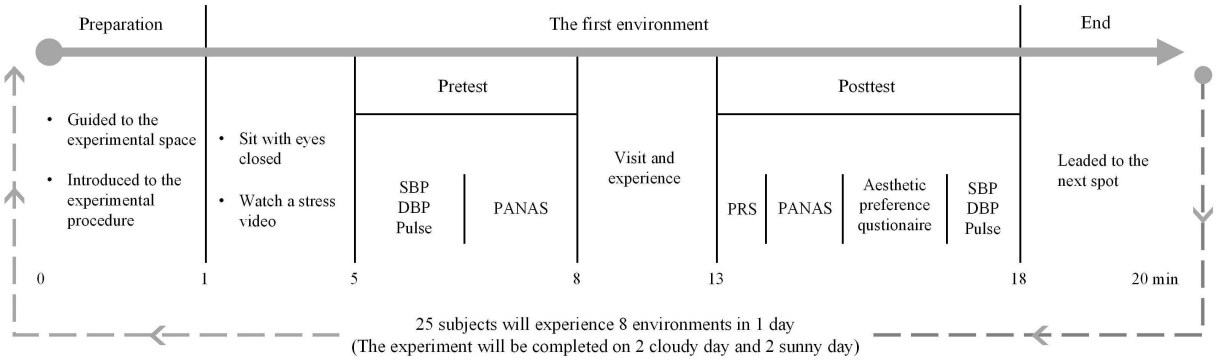

FIGURE 2
Experimental flowchart.

measurements and completed positive and negative affect schedule (PANAS). Ulrich (48) found obvious physical and mental recovery after 3–5 min of contact with the natural environment; thus, after completing the questionnaire, the participants experienced in the experimental area for approximately 5 min. They were allowed to walk and sit but were instructed not to talk to others or look at electronic devices. After the visiting experience, the participants completed the perceived restorativeness scale (PRS) and PANAS and answered two questions about their aesthetic preferences. The researchers then measured and recorded their physiological indicators again. We mitigated the discomfort caused by the constriction of the blood pressure cuff by maximizing the interval between the two blood pressure measurements. After completing a space experiment, researchers led participants to the next space; and the same process was repeated at each space (Figure 2). The demographic characteristics of the participants were collected in advance of the experiment.

2.4. Measurements

2.4.1. Physiological measures

Blood pressure is a crucial indicator of physical health status, capable of reflecting states of alertness or relaxation. Simultaneously, blood pressure measurement possesses the advantages of high portability, meeting outdoor experimental demands, and imposing a smaller burden on participants. Therefore, blood pressure was ultimately selected as the physiological measurement index for restoration. In the experiment, systolic blood pressure (SBP; mmHg), diastolic blood pressure (DBP; mmHg), and pulse (bpm) were measured on the subjects' left arm using a portable electronic blood pressure monitor (Omron, HEM-7011, China). Physiological measurements were conducted both before and after each spatial experience.

2.4.2. Psychological measures

Based on ART and SRT, the association between UGS and psychological health primarily pertains to perceived restoration and emotional recovery. For emotional recovery, we selected the Positive and Negative Affect Schedule (PANAS), a well-established scale for measuring positive affect (PA) and negative affect (NA), which has been comprehensively documented for its reliability and validity (49). The PANAS measures positive affect (PA) and negative affect (NA) using 10 items each (a total of 20 items). The scale ranges from 1 (very slightly) to 5 (extremely) to rate the subjective feelings of the participants, with higher scores representing stronger emotional experiences. We conducted PANAS assessments before and after each space experience (Supplementary Table S1).

In terms of perceived restoration, the currently predominant measurement method is the Perceived Restorative Scale (PRS). It assesses the quality of environment restorativeness along 4 characteristic dimensions in ART (16): being away (i.e., escaping from the routine aspects of one's life), fascination (a scene or object interesting enough to hold one's attention), compatibility (match between an individual's needs or desires and what the environment offers) and extent (there are various exhibits and displays to explore in this setting). To prevent participant fatigue, a short version of the revised PRS by Hartig et al. (50) and Huang et al. (51) was selected; it has a total of 18 items (Supplementary Table S2).

Two aesthetic preference questions were used to assess the participants' aesthetic preferences for the current sky and environment. To avoid ambiguity, the sky aesthetic preference in the questionnaire was defined as "the sky is beautiful enough to attract people," and the environmental aesthetic preference was defined as "the scenery is beautiful enough to attract people." The two specific questions were as follows: (1) "Look at the sky. How would you rate the beauty of the sky at this moment?" and (2) "Look around. How would you rate the beauty of the environment at this moment?" These items were scored on a 5-point Likert scale (Supplementary Table S3).

2.5. Statistical analysis

The Mann–Whitney U test and Kruskal–Wallis test were used to analyse the demographic characteristics of participants. A paired t test was used to analyse physiological data. The Wilcoxon signed-rank test and Kruskal–Wallis test were used to analyse aesthetic preferences and psychological data. The statistical analysis was performed with SPSS 27.0 (SPSS Inc., Chicago, IL, United States), and a p <0.05 was considered to indicate statistical significance.

3. Results

3.1. Demographic characteristics

The analysis of demographic characteristics is shown in Figure 3. There were equal numbers of male and female participants in this experiment, and almost half of all participants were aged 19 or 20 years. In terms of educational background, undergraduate participants accounted for more than 70% of the sample, and there were half as many participants majoring in landscape architecture as participants with a different major. Regarding region, 20% of the participants were from Chengdu, and 80% were from other regions.

As shown in Table 2, sex had a significant impact on the aesthetic preference and psychological restorativeness of UGSs. Women had a stronger aesthetic preference under the sunny condition ($Z = -2.699$, $p < 0.01$), and UGSs had greater psychological restorativeness for women under both weather condition (sunny [$Z = -3.559$, $p < 0.001$]; cloudy [$Z = -3.176$, $p < 0.01$]). Compared with participants from other

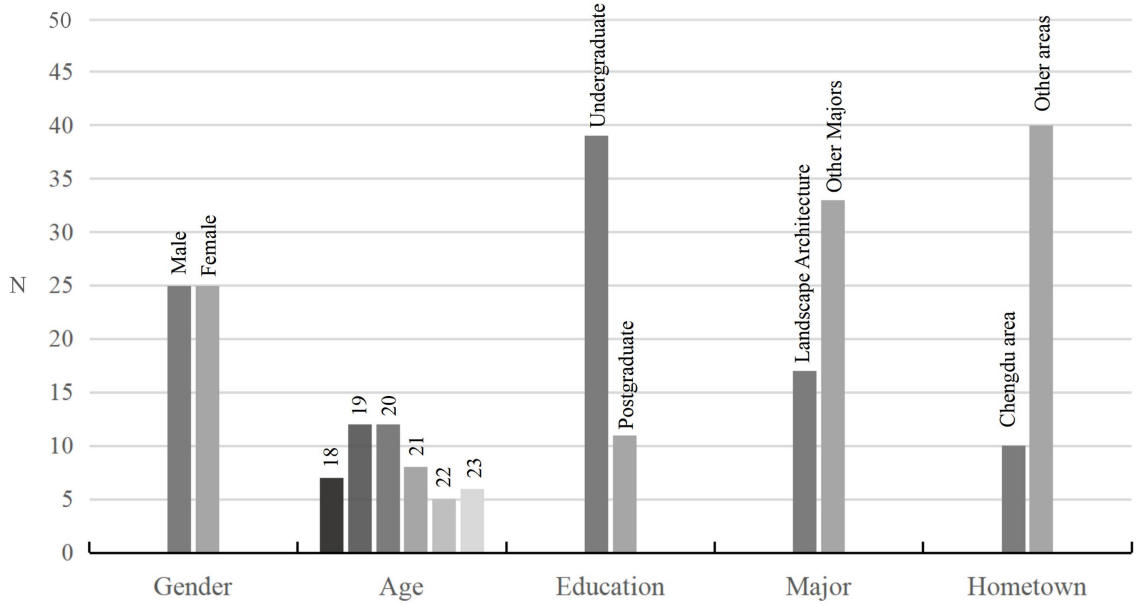

FIGURE 3
Demographic characteristics of participants.

TABLE 2 The relationships among demographic characteristics, aesthetic preferences and perceived restoration.

Demographic characteristics ($N = 50$)		Aesthetic preference (Cloudy)		Aesthetic preference (Sunny)		Perceived restoration (Cloudy)		Perceived restoration (Sunny)	
		Mean rank	*p*	Mean rank	*p*	Mean rank	*p*	Mean rank	*p*
Sex	Male	199.22	0.812	185.90	0.007**	182.15	0.001**	179.93	0.000***
	Female	201.79		215.10		218.86		221.07	
Age	18	213.50	0.826	185.13	0.411	182.20	0.714	184.29	0.234
	19	190.36		216.73		208.10		208.44	
	20	201.72		193.92		196.41		181.87	
	21	195.78		193.30		213.02		223.59	
	22	199.81		192.63		205.36		202.59	
	23	210.04		215.29		194.09		208.27	
Education	Undergraduate	195.28	0.069	201.18	0.814	206.64	0.052	199.29	0.692
	Postgraduate	219.02		198.10		181.74		204.81	
Major	Landscape architecture	204.96	0.558	203.35	0.708	199.26	0.879	214.14	0.094
	Other	198.25		199.06		201.13		193.63	
Hometown	Chengdu	178.41	0.039*	209.74	0.389	199.26	0.052	213.22	0.267
	Other region	206.11		198.15		201.13		197.27	

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

TABLE 3 Sky aesthetic preference and environment aesthetic preference under two weather conditions.

Variable		*N*	Median (IQR)	*Z*	*p*
Sky aesthetic preference	Cloudy	400	2.00 (2.00–3.00)	−11.46	0.000***
	Sunny	400	4.00 (2.00–4.00)		
Environment aesthetic preference	Cloudy	400	3.00 (3.00–4.00)	−4.42	0.000***
	Sunny	400	4.00 (3.00–4.00)		

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. IQR, interquartile range.

regions, participants from the Chengdu region had a significantly lower aesthetic preference for UGSs on cloudy days ($Z = -2.060$, $p < 0.05$).

3.2. Aesthetic preference

The Wilcoxon signed-rank test showed (Table 3) that subjects' aesthetic preferences for the sky and environment on sunny days were significantly higher than those on cloudy days (sky [$Z = -11.46$, $p < 0.001$]; environment [$Z = -4.42$, $p < 0.001$]).

The Kruskal–Wallis test revealed significant differences in the mean aesthetic ratings among the 8 spaces under the two weather conditions (cloudy [$H = 32.357$, $df = 7$, $p < 0.001$]; sunny [$H = 27.622$, $df = 7$, $p < 0.001$]). Under the cloudy condition, spaces 2, 3, and 4 had higher aesthetic preference scores, and space 4 had the highest score (Table 4A). Under sunny conditions, spaces 2, 3, and 4 had higher aesthetic preference scores, and space 2 had the highest score (Table 4B).

3.3. Physiological results

The physiological indicators suggested that participants were more relaxed after visiting the 8 UGSs on sunny days than on cloudy days (Table 5). The paired t test showed that the pulse of participants after the UGS experience was significantly lower in the sunny condition than that in the cloudy condition (72.97 ± 10.89 and 74.13 ± 10.20, respectively; $t = 2.169$, $p < 0.05$). Participants' SBP and DBP did not significantly differ between sunny days and cloudy days (SBP [119.04 ± 13.30 and 119.92 ± 12.17, $t = 1.536$, $p = 0.125$]; DBP [76.32 ± 9.00 and 76.87 ± 9.11, $t = 1.292$, $p = 0.197$]).

As shown in Figure 4, participants' SBP, DBP and pulse decreased after visiting the 8 spaces on cloudy days; however, only 2 spaces produced a significant decrease in these physiological indicators. SBP (120.70 ± 11.99 and 117.16 ± 11.93, $t = 3.87$, $df = 49$, $p < 0.01$) and DBP (78.80 ± 8.07 and 76.66 ± 8.72, $t = 2.46$, $df = 49$, $p < 0.05$) were significantly decreased after visiting space 8. DBP (79.26 ± 8.10 and 77.20 ± 7.66, $t = 2.07$, $df = 49$, $p < 0.05$) was significantly decreased after visiting space 1.

TABLE 4 Aesthetic preferences of 8 environments types in two weather conditions ($N = 50$).

A. Cloudy condition								
	Space 1	Space 2	Space 3	Space 4	Space 5	Space 6	Space 7	Space 8
Median (IQR)	3 (3–4)	4 (3–4)	4 (3–4)	4 (3–4)	3 (3–4)	3 (3–4)	3 (3–4)	3 (3–4)
Mean rank	159.24	230.47	221.51	256.79	188.19	170.02	188.98	188.8
Ranking	8	2	3	1	6	7	4	5
B. Sunny condition								
Median (IQR)	3 (3–4)	4 (3–5)	4 (3–4)	4 (3–4.25)	3 (3–4)	4 (3–4)	4 (3–4)	3 (3–4)
Mean rank	155.1	243.75	220.28	223.95	170.95	207.79	206.80	175.38
Ranking	8	1	3	2	7	4	5	6

IQR, interquartile range. A rank has been awarded to each space based on the mean rank.

TABLE 5 Comparison of SBP, DBP, and pulse after experiencing UGSs under the two weather conditions.

Variable		N	M	SD	t	p
SBP	Cloudy	400	119.92	12.17	1.536	0.125
	Sunny	400	119.04	13.30		
DBP	Cloudy	400	76.87	9.11	1.292	0.197
	Sunny	400	76.32	9.00		
Pulse	Cloudy	400	74.13	11.20	2.169	0.031*
	Sunny	400	72.97	10.89		

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. M, mean value; SD, standard deviation.

As shown in Figure 5, participants' physiological indicators decreased after visiting the 8 spaces on sunny days, and 5 spaces produced a significant decrease in these indicators. Specifically, SBP (121.58 ± 12.69 and 117.57 ± 12.12, $t = 3.86$, $df = 49$, $p < 0.01$) and pulse (75.50 ± 11.30 and 73.16 ± 11.11, $t = 2.75$, $df = 49$, $p < 0.01$) were extremely significantly decreased after visiting space 1. SBP (120.70 ± 13.87 and 118.52 ± 14.48, $t = 2.09$, $df = 49$, $p < 0.05$) and DBP (76.02 ± 9.74 and 74.06 ± 9.89, $t = 2.26$, $df = 49$, $p < 0.05$) were significantly decreased after visiting at space 4. SBP (122.40 ± 13.24 and 119.68 ± 12.15, $t = 2.83$, $df = 49$, $p < 0.01$) decreased significantly after visiting space 7; pulse (74.50 ± 9.90 and 72.32 ± 11.45, $t = 2.33$, $df = 49$, $p < 0.05$) decreased significantly after visiting space 3, and SBP (122.72 ± 12.43 and 120.14 ± 12.19, $t = 2.38$, $df = 49$, $p < 0.05$) was significantly decreased after visiting space 6.

3.4. Psychological results

3.4.1. Emotional recovery

After visiting the 8 spaces in two weather conditions, participants exhibited stronger emotional restoration on sunny days. The Wilcoxon signed-rank test (Table 6) showed that the participants' PA scores after visiting UGSs under the sunny condition were significantly higher than those under the cloudy condition ($Z = -10.299$, $p < 0.001$). There were no significant differences in NA scores between sunny and cloudy days ($Z = -0.861$, $p = 0.389$).

As shown in Figure 6A, after visiting spaces 3 and 4 under the cloudy condition, PA scores were significantly increased, and NA scores were significantly decreased. PA scores significantly increased after visiting space 6, and NA scores significantly decreased after visiting spaces 1, 2, and 7. As shown in Figure 6B, PA scores increased and NA scores decreased after visiting the 8 spaces under the sunny condition. After visiting spaces 2, 6, and 7, PA scores were significantly increased, and NA scores were significantly decreased. NA scores decreased significantly after visiting spaces 4, 5 and 8.

3.4.2. Perceived restoration

The Wilcoxon signed-rank test (Table 7) showed that the scores of each dimension of perceived restoration (being away [$Z = -2.059$, $p < 0.05$], extent [$Z = -3.290$, $p < 0.01$], fascination [$Z = -3.291$, $p < 0.01$], and compatibility [$Z = -2.280$, $p < 0.01$]) and the overall restorative potential ($Z = -3.224$, $p < 0.01$) of spaces were significantly higher on sunny days than on cloudy days.

The PRS scores of each space under the cloudy condition are shown in Table 8A. The Kruskal–Wallis test demonstrated that there were significant differences in the "being away" ($H = 25.893$, $p < 0.01$) and overall restorative potential ($H = 14.820$, $p = 0.038$) among the 8 spaces, but there were no significant differences in other dimensions. Overall, spaces 2 and 4 had a positive effect on perceived restoration under the cloudy condition.

The PRS scores of each space under the sunny condition are shown in Table 8B. The Kruskal–Wallis test demonstrated that there were significant differences in "being away" ($H = 32.677$, $p < 0.001$), fascination ($H = 15.945$, $p = 0.026$) and overall restorative potential ($H = 16.041$, $p = 0.025$) among the 8 spaces, but there were no significant differences in other dimensions. Overall, spaces 2 and 4 had a positive effect on perceived restoration under the sunny condition.

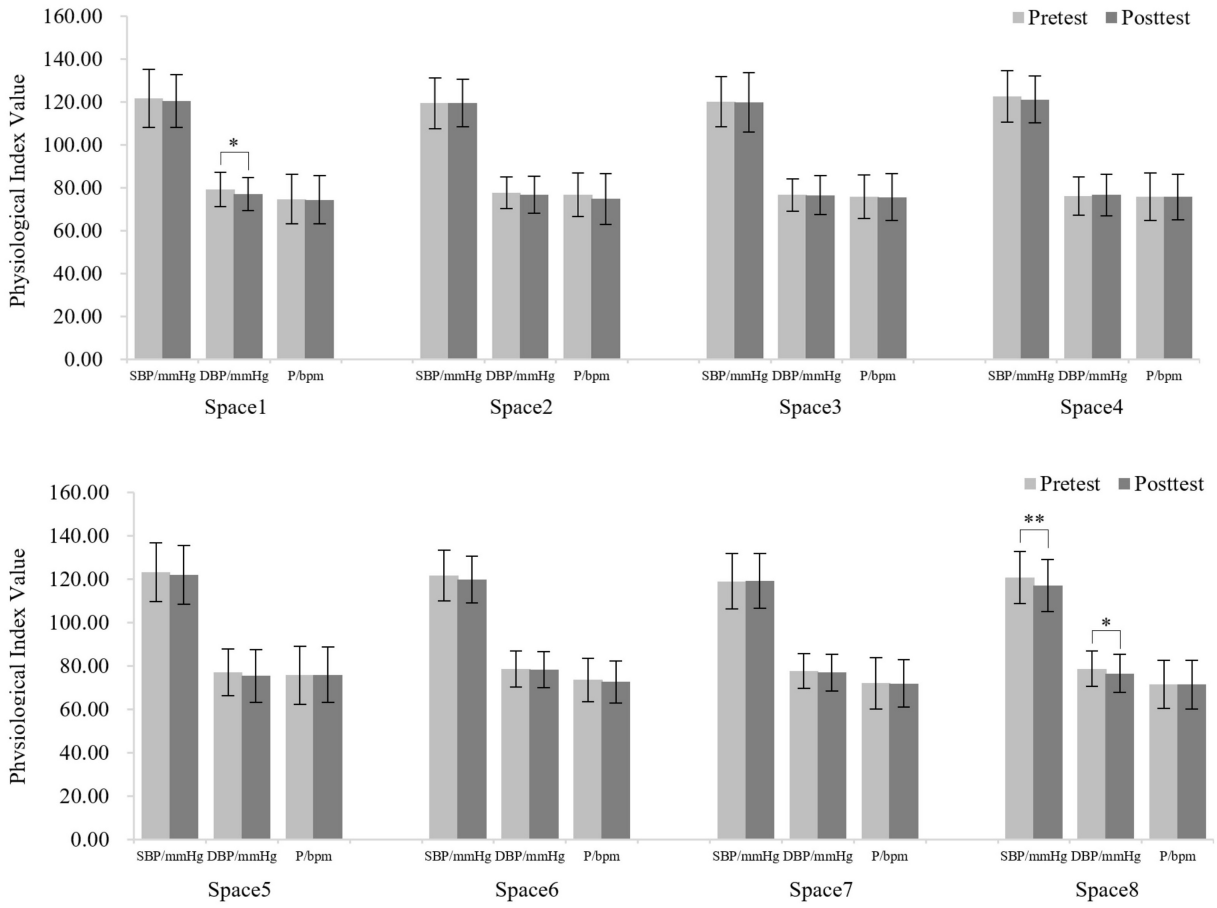

FIGURE 4
Blood pressure and pulse values before and after visiting the 8 spaces on cloudy days. $N = 50$. Values shown are the mean ± SD. *$p < 0.05$, **$p < 0.01$.

4. Discussion

4.1. Demographic characteristics

Previous studies have shown that women have stronger aesthetic preferences for green spaces (52). However, we did not obtain similar results under cloudy conditions. Lis et al. demonstrated that perceived danger plays a significant mediating role in the process where the environment influences preference in natural settings (53). Generally, women are more sensitive to their surroundings (54) and are more concerned about the safety of dimly lit environments (55). Cloudy weather with poor sunlight may trigger nocturnal fears (38), and thereby influence women's aesthetic preferences for UGSs under overcast conditions.

Under both weather conditions, women's perceived restoration potential was stronger than that of men. This supports previous findings that women experience better stress recovery (56), vitality (57), and emotional improvement (58) in UGSs. Our study further confirms that UGSs can better promote women's perceived restoration. This may be attributed to women's lower self-reported vitality in daily life (57) and their greater awareness of the health benefits of natural environments (56), making them more in need of restorative environments and more receptive to the benefits of nature.

In addition, the results showed that compared with subjects from other regions, those from the Chengdu area were less pleased with the cloudy condition. von Lindern (59) proved that the weaker the perceived setting interdependencies between the environment and crowds, the stronger the sense of being away and the restorativeness of the environment. Considering that there are significantly more cloudy days in Chengdu than in other regions, subjects from Chengdu will have a weaker sense of being away on cloudy days; thus, they have a lower preference for UGSs on cloudy days.

4.2. Aesthetic preference

The results showed that people prefer sunny sky and that the aesthetic ratings of each space were higher on sunny days than on cloudy days. Beute and de Kort (4) proposed that sunny days are more likely to trigger positive associations (with summer, weekends, or holidays) than cloudy days ($F = 30.9$, $p < 0.001$); this may explain why people preferred sunny sky in the present study.

We further compared the preference scores of each space under the two weather conditions and found that spaces 2 and 4 (which had high naturalness and low SVF) had higher aesthetic ratings on cloudy and sunny days, with ratings higher than those of spaces 1 and 5 (which had low naturalness and low SVF). Naturalness was the

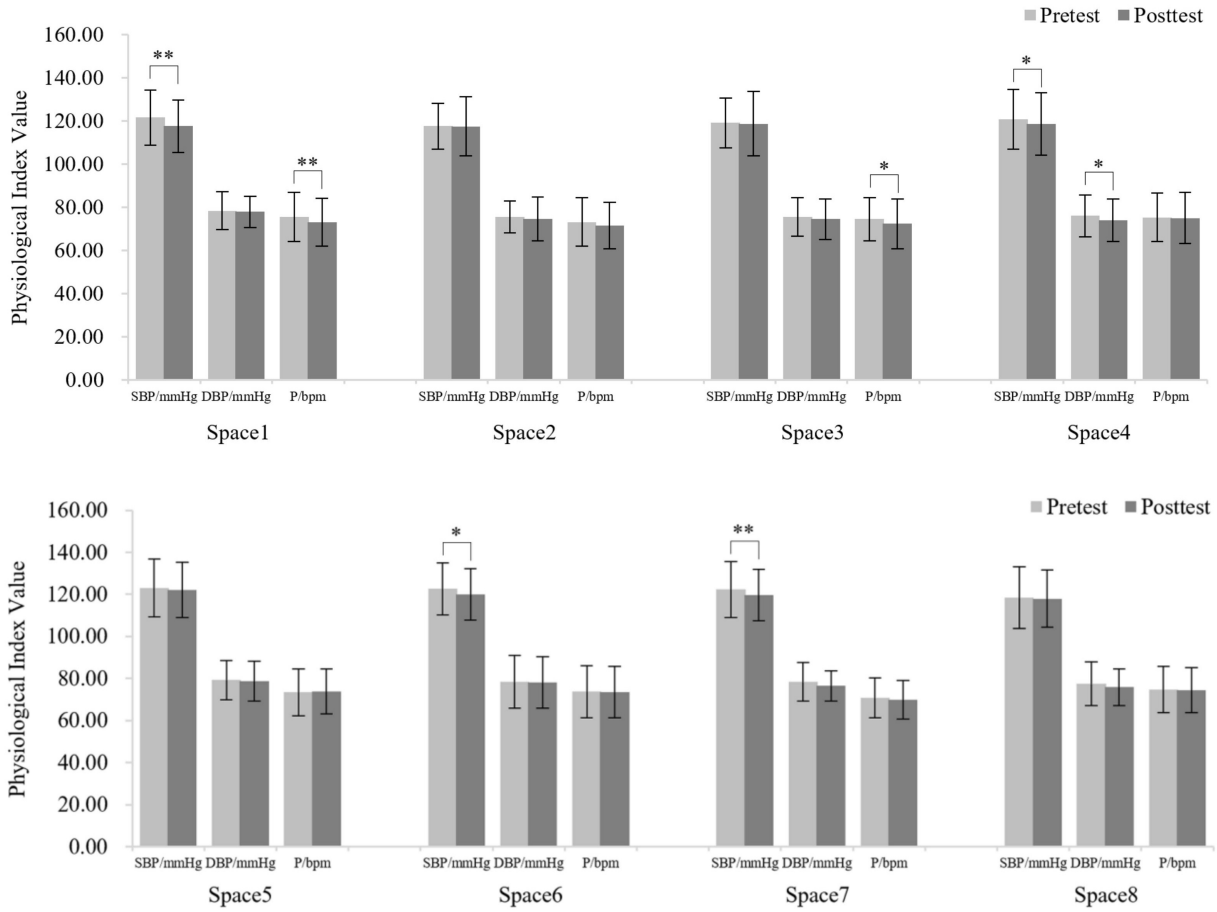

FIGURE 5
Blood pressure and pulse values before and after visiting the 8 spaces on sunny days. $N = 50$. Values shown are the mean ± SD. $^{*}p < 0.05$, $^{**}p < 0.01$.

TABLE 6 Comparison of PA and NA scores after visiting UGSs under the two weather conditions.

Variable		*N*	Median (IQR)	*Z*	*p*
PA score	Cloudy	400	23.00 (17.25, 28.00)	−10.299	0.000***
	Sunny	400	27.00 (20.25, 33.00)		
NA score	Cloudy	400	11.00 (10.00, 14.00)	−0.861	0.389
	Sunny	400	11.00 (10.00, 14.00)		

$^{*}p < 0.05$, $^{**}p < 0.01$, $^{***}p < 0.001$. IQR, interquartile range.

measured environment feature that differed between the two types of environments, further indicating that people have a stronger aesthetic preference for natural environments (17). This may be because individuals are more likely to approach nature in natural environments than in artificial environments. According to biophilia theory (60), humans have an innate impulse to approach and connect with nature; thus, an environment with higher naturalness may evoke stronger aesthetic preferences in both weathers.

4.3. Physiological relaxation

The results showed that the physiological restoration benefits of UGSs were enhanced on sunny days compared to cloudy days. Previous studies have demonstrated that sunlight has cardioprotective and antihypertensive effects (35–37). Our study tested this notion and further found that sunlight exposure led to a significant decrease in pulse, resulting in greater physiological recovery when visiting UGSs on sunny days.

We found that spaces with water bodies improved physiological recovery under both weather conditions (cloudy [spaces 1 and 8]; sunny [spaces 1, 3, and 4]). This may be because water bodies make it easier for people to achieve a state of calm and relaxation by improving the microclimate (38). We also found that spaces with high SVF (space 3, 6, and 7) led to greater physiological recovery on sunny days than on cloudy days. Benita and Tunçer (24) found that UGSs with higher sky exposure tended to reduce physiological stress. Our study supports this result and

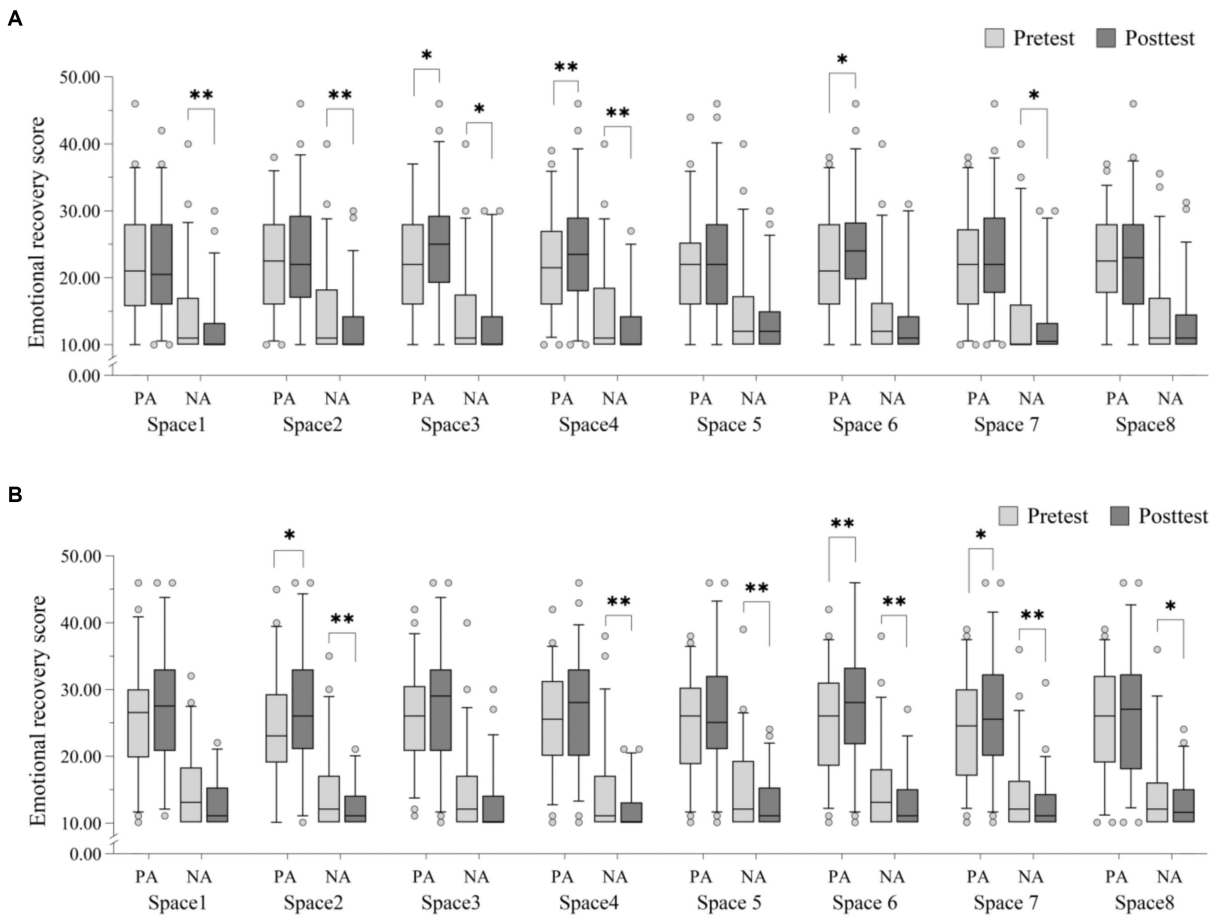

FIGURE 6
PANAS subscale scores before and after visiting 8 spaces under the two weather conditions. **(A)** Cloudy condition; **(B)** sunny condition. *N* = 50. Data shown are the median (central line), interquartile range (box margins), adjacent values (whiskers), and outliers (dots). *$p < 0.05$, **$p < 0.01$.

TABLE 7 Comparison of perceived restoration scores under the two weather conditions.

Variable		*N*	Median (IQR)	*Z*	*p*
Being away	Cloudy	400	4.40 (3.60–5.20)	−2.059	0.040*
	Sunny	400	4.40 (3.80–5.40)		
Extent	Cloudy	400	4.50 (3.75–5.25)	−3.290	0.001**
	Sunny	400	4.75 (4.00–5.50)		
Fascination	Cloudy	400	4.25 (3.50–5.00)	−3.291	0.001**
	Sunny	400	4.63 (4.00–5.50)		
Compatibility	Cloudy	400	4.40 (3.60–5.15)	−2.280	0.005**
	Sunny	400	4.60 (4.00–5.40)		
Overall restorative potential	Cloudy	400	4.34 (3.68–5.11)	−3.224	0.001**
	Sunny	400	4.58 (4.00–5.28)		

*$p < 0.05$, **$p < 0.01$, ***$p < 0.001$. IQR, interquartile range.

further demonstrated that the physiological restoration effect of such environments is stronger on sunny days. One possible explanation is that a higher SVF increases exposure to sunlight on sunny days, and exposure to sufficient sunlight reduces physiological stress through underlying physiological mechanisms (61). Additionally, a higher SVF indicates an increased proportion of sky in the field of view. Due to the positive correlation between aesthetic preference and restoration benefits (18, 62), people's preference for blue sky on sunny days mediates the recovery benefits of this environment type.

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TABLE 8 Perceived restoration effect of different UGSs under the two weather conditions ($N = 50$).

A. Cloudy condition									
		Space 1	Space 2	Space 3	Space 4	Space 5	Space 6	Space 7	Space 8
Being away	Mean rank	161.26	254.86	182.86	227.19	186.07	169.84	211.27	210.65
	Ranking	8	1	6	2	5	7	3	4
Extent	Mean rank	181.83	222.31	198.47	228.59	183.89	185.46	197.69	205.76
	Ranking	8	2	4	1	7	6	5	3
Fascination	Mean rank	179.29	224.13	207.98	232.04	180.36	187.91	190.55	201.74
	Ranking	8	2	3	1	7	6	5	4
Compatibility	Mean rank	168.48	235.63	203.30	228.53	188.90	179.06	198.92	201.18
	Ranking	8	1	3	2	6	7	5	4
Overall restoration	Mean rank	170.32	237.37	197.00	230.79	184.08	179.17	198.99	206.28
	Ranking	8	1	5	2	6	7	4	3
B. Sunny condition									
Being away	Mean rank	151.98	259.74	168.14	221.94	200.11	171.5	220.62	209.97
	Ranking	8	1	7	2	5	6	3	4
Extent	Mean rank	170.02	223.67	214.04	219.86	182.24	188.95	203.55	201.67
	Ranking	8	1	3	2	7	6	4	5
Fascination	Mean rank	168.08	219.57	226.65	229.12	168.85	183.54	202.36	205.83
	Ranking	8	3	2	1	7	6	5	4
Compatibility	Mean rank	164.81	219.82	194.29	221.46	184.42	190.83	210.62	217.75
	Ranking	8	2	5	1	7	6	4	3
Overall restoration	Mean rank	159.18	234.22	199.58	224.55	182.47	182.43	210.06	211.51
	Ranking	8	1	5	2	6	7	4	3

Verified by the Kruskal–Wallis test. A rank was awarded to each space based on the mean rank.

4.4. Psychological restoration

The results showed that people's positive emotions and perceived restoration after visiting UGS were better on sunny days than on cloudy days. This supports the findings of Ulrich's study that positive responses to nature may be enhanced by sunlight due to long-term evolutionary adaptations to sunlight (31). For example, a sunny environment is associated with less danger and less psychological stress and tension than an overcast environment. Different weather conditions provide different emotional cues; sunny days are often associated with more positive emotions (63, 64). Therefore, UGSs may have better psychological restoration effects on sunny days. NA scores were not significantly reduced in this study, which is consistent with a meta-analysis by McMahan and Estes (11), which found that PA scores increased (dependent on condition) but NA scores did not (Q [19] = 21.86, $p = 0.29$). Mei et al. (5) also found that meteorological factors do not affect NA (solar radiation [$r = 0.006$, $p > 0.05$]). In this study, most of the participants were interviewed after the experiments. They reported that they felt more relaxed after viewing scenery in the two weather conditions and did not experience much negative emotion. Therefore, there was no significant difference in NA scores between sunny and cloudy days.

In terms of emotional recovery, the data show that spaces with water bodies (space 1, 3, and 4) had stronger emotional recovery effects on cloudy days and that spaces without water bodies (space 2, 5, 6, 7) had stronger emotional recovery effects on sunny days. Thus, the presence of a water body was the main feature affecting emotional recovery under the two weather conditions, and emotional recovery effects due to viewing the water body were stronger on cloudy days. This contradicts the findings of White et al. (38), who argued that water bodies provide greater recovery under the sunny condition. Our hypothesis is that calm water is more likely to improve mood on cloudy days, and positive mood is more likely to be associated with flowing water on sunny days. The experimental season was conducted in autumn in Chengdu, during which time the water is relatively calm, and overall water flow is slow. From an evolutionary and circadian perspective, organisms are better adapted to being in quieter environments when the light is darker (65); thus, viewing serene water bodies may have a greater effect on emotional recovery on cloudy days. On sunny days, the restorativeness of the waterscape may come from experiencing light reflected off of the fluctuating water surface (66) and the sound of running water (20, 67). The calm river water in this study may have limited the restorative potential of spaces with water bodies, resulting in spaces without water bodies exhibiting greater emotional restorativeness on sunny days. The differences in restorative effects of spaces with and without water bodies under different weather conditions can be further explored in the future.

The perceived restoration effects of sunny and cloudy days were highly consistent. Under both weather conditions, higher PRS scores were observed in spaces with high naturalness (space 2, 4,

8, and 7), while lower PRS scores were observed in spaces with low naturalness (space 1, 3, 5, and 6). The data suggest that UGSs with high naturalness are perceived as more restorative under both weather conditions, a finding that is consistent with those of many previous studies (12, 13). Among the spaces, spaces 2 and 4, which had high naturalness and low SVF, exhibited greater perceived restoration under the two weather conditions. Previous studies have demonstrated that the amount of sky visible can enhance fascination, with a weak positive correlation observed between fascination and perceptual recovery (effects = 0.283, $p < 0.01$) (23, 68). This partially contradicts our findings. Our results showed that space 2 and 4 were rated as significantly higher in being away and high in fascination. We believe that this may be because lower SVF in a natural environment creates a sense of privacy, which can trigger daydreams that differ from daily work and life and unconsciously restore directed attention; the diversity and complexity of the natural environment may also promote fascination (67). The results of perceived restoration are consistent with the results of aesthetic preference, which supports a correlation between environment preference and perceived restoration (9, 10).

4.5. Combined physiological and psychological restoration

After a comprehensive observation of the combined physiological and psychological restoration effects across environments in two weather conditions, we found that space 1 (low naturalness, low SVF and with bodies of water) promoted physio-psychological restoration (physiological and emotional recovery) on cloudy days, and space 4 (high naturalness, low SVF and with bodies of water) promoted physio-psychological restoration (physiological, emotional and perceived restoration) on sunny days.

The results above show that an environment with a low SVF and bodies of water can promote the recovery of physiological and psychological health simultaneously in both weather conditions. Some possible explanations are that a lower SVF on sunny days is correlated with increased shading, while bodies of water increase the humidity. Together, these two factors improve microclimate comfort (24, 38), which is beneficial for relieving stress on sunny days and achieving physical and mental relaxation. In contrast to previous studies, White et al. (38) found that the effect of bodies of water on recovery on cloudy days was significantly lower than that on sunny days, possibly because areas with bodies of water have fewer opportunities to provide shelter in bad weather. However, combined with the results of this study, it may be proven that in cloudy environments that provide a low sense of security, a lower SVF increases the sense of enclosure and shelter of the environment (including bodies of water) as well as the greenery people are exposed to in UGSs (26). These two aspects could affect physio-psychological recovery by promoting physical activity (69), releasing tension (7) and aiding visitors in recovering the directed attention (6). Therefore, such environments also show good health recovery potential under cloudy conditions. The SVF results support previous findings that the restoration effect of green spaces does not always increase with the SVF (26, 46, 70). Although studies have shown that public physical and mental health generally improve with increasing SVF score (25, 71), our research may demonstrate that the restoration effect of UGSs does not always correlate negatively with the reduction in the SVF until it decreases to a certain threshold. Quantitative and in-depth research on SVF should be conducted in the future to assess the specific boundaries and characteristics of SVF that affect the restoration of UGSs.

4.6. Limitations

The limitations are as follows. Firstly, we chose completely cloudy and completely sunny days for the experiment. In future research, more weather types (e.g., partly cloudy) should be considered, and quantitative indicators such as illuminance and sun elevation angle should be incorporated. Additionally, each participant had to visit all 8 spaces and complete many questionnaires in 1 day in our study, which reduced the scientificity and reliability of the data. Moreover, the physiological status of participants may change from before to after lunch, which could have induced errors in the measurement of physiological indicators such as blood pressure. Finally, the study only focused on one park in Chengdu and conducted experiments in only one season. Perceptions of environmental temperature by participants may vary at different latitudes due to various factors such as adaptability. Perception of weather conditions might also be influenced by the season. Subsequent research should explore a broader range of experimental locations and seasons to enhance the universality of the research.

5. Conclusion

Until now, most studies have only focused on the influence of green space characteristics on restoration. This study innovatively broadened its scope by investigating weather factors (sunny and cloudy conditions), thus expanding the research domain of UGS restorative environments and introducing the notion of "comprehensive restorative environments." This expansion offers a more scientifically grounded theoretical basis for the establishment and enhancement of restorative environments in diverse weather conditions across different regions. As evidenced by the findings, weather conditions do indeed impact restorative benefits. For instance, UGSs exhibit greater health recovery potential on sunny days compared to overcast ones, with females experiencing stronger psychological recovery benefits under both weather conditions. Moreover, there are also variations in restorative effects among different environmental types under two weather conditions. These conclusions provide new insights for research on health-supportive human habitats in the context of global climate change, offering nature-based solutions to meet the residents' escalating demands of health restoration.

In future planning and design practices, UGSs in regions with frequent cloudy days should incorporate more water bodies with gentle flow and low gradient, as this proves to be an effective approach to enhance emotional restoration during overcast weather. UGSs in regions with frequent sunny days should consider increasing sky exposure while ensuring adequate shading to

promote residents' physical health. Additionally, sheltered environments that incorporate water bodies demonstrate the capacity to promote both physical and mental health restoration under both weather conditions, rendering them suitable for widespread implementation across various regions. Furthermore, the study also unveiled that the restorative benefits of water bodies might be influenced by factors other than weather, such as water flow conditions. Likewise, a more intricate relationship could potentially exist between sky openness and health restoration. Future research should delve deeper into these intriguing matters.

Data availability statement

The datasets presented in this article are not readily available because protecting the privacy of the participants. Requests to access the datasets should be directed to XL, lixi@sicau.edu.cn.

Ethics statement

The studies involving humans were approved by Ethics Committee of the College of Landscape Architecture, Sichuan Agricultural University, China. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

SC: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Visualization, Writing – Original draft, Writing – Review & editing. ZS: Conceptualization, Investigation, Methodology, Writing – Review & editing. XL: Funding acquisition, Supervision, Writing – Review & editing. HL, LS, MJ, JD, EF, JM, NL, BG, XY, BL, JW: Writing – Review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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.2023.1258848/full#supplementary-material

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Five ways to wellbeing at the zoo: improving human health and connection to nature

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Good mental and physical health go hand-in-hand when identifying factors that lead people to experience a better overall quality of life. A growing disconnect to the natural world is worsening the mental health of individuals in many societies. Numerous scientific publications have evidenced that being in nature and access to green and blue spaces positively impact upon humans' physical and mental health. For many people, particularly those living in more urbanized areas, managed natural spaces and borrowed landscapes, such as those found in public parks, wildlife reserves and zoological gardens give the only opportunities for wider engagement with nature. Many zoos are designated green spaces and therefore human visitors can engage with native fauna and flora as well as exotic wild animals. This article reviews the UK Government's "The Five Ways to Wellbeing" concept, applied to zoos and aquariums and thus suggests how zoos and aquariums can use this framework to promote positive nature-connectivity experiences for their visitors and promote good wellbeing. The Five Ways to Wellbeing are Connect, Be active, Take notice, Keep learning, and Give. We illustrate how zoos and aquariums could model their approaches to educational and engagement roles, as well as design initiatives to reach out to local communities *via* the Five Ways to Wellbeing concept. We show that many of the positive programs and works conducted by zoos and aquariums lend themselves to further engagement with the Five Ways to Wellbeing structure. By taking such a structured approach in the design, implementation and evaluation of their activities, zoos can expand their abilities in connecting humans with nature and further add value to their living collections of animals and plants. By including Wellbeing as a defined aim of the modern zoo, it will be clear to all of those involved in their work, visitors, workers, stakeholders, that zoos are working to promote, protect and preserve positive wellbeing outputs for humans and animals alike.

KEYWORDS

animal welfare, human wellbeing, nature connection, zoo, mental health

1. Introduction

There is a global crisis around mental health (Patel et al., 2007; Tiwari, 2023), in part caused by contemporary challenges to living (Jakovljevic et al., 2020) modern ways of communicating and living (Kelly et al., 2018; Smith and Victor, 2019), and a widespread disconnection with nature and the natural world (Gelsthorpe, 2017). Access to nature has been shown to promote positive wellbeing and alleviate mild depression and anxiety in humans (Bratman et al., 2012; Keenan et al., 2021; Owens and Bunce, 2022; Irvine et al., 2023). As global populations continue

to urbanize (United Nations, 2018), causing greater distance between centers of human habitation and wild environments (Cox et al., 2018), managed green and blue spaces (e.g., public parkland and gardens and nature-themed visitor attractions such as zoological collections) become more important to fostering a sense of "being in nature" (Baur and Tynon, 2010; Kellert, 2012; Arbuthnott et al., 2014; Taylor and Duram, 2021). Institutions that are ultimately centered on bringing nature closer to humans are zoological collections, such as zoos, aquariums, and safari parks (hereafter "zoos"). Although the number is hard to accurately define, there are an estimated 10,000 zoological collections globally (Glazier, 2017). A smaller proportion of this overall estimate will be part of accreditation (e.g., European Association of Zoos & Aquaria, EAZA; Association of Zoos & Aquariums, AZA) or membership (British & Irish Association of Zoos & Aquariums) organizations that uphold education, conservation and research initiatives and promote good animal welfare (Marcy, 2021; BIAZA, 2023a; EAZA, 2023a). Modern zoos are consistently aiming to promote both animal welfare and positive human wellbeing in terms of their outputs and operations (Rose and Riley, 2022) and therefore have value to the human populations that work at them, live around them, visit them and engage with their work on a local or global level (Greenwell et al., 2023). This value can be extended if zoo visits can enhance mental health, encourage a deeper understanding of nature, and foster a greater appreciation of the natural world.

The UK government defines the concept of human wellbeing as comprising of two main elements: feeling good and functioning well (CIEEM, 2021). This approach is similar to that outlined by the World Health Organization, who state that wellbeing is a positive state experienced by individuals and societies, that is important for daily life, and encompasses quality of life and the activities that people can get involved in World Health Organisation (2023). Therefore, enhancing opportunities to be outdoors with nature, and to engage with others whilst undertaking meaningful and fulfilling activities promotes these good feelings and positive physical and mental functions (Nisbet et al., 2011; Bratman et al., 2012; Cudworth and Lumber, 2021), which are the core of wellbeing.

An example of an approach to enhance human wellbeing to improve overall quality of life can be found in the Five Ways (or Steps) to Wellbeing that were published in 2008 by the New Economics Foundation on behalf of the UK Government (Aked et al., 2008b). This project was initiated to understand ways of promoting improvements to mental wellbeing in individual people and across society more widely, and of enhancing mental capital (i.e., a person's cognitive and emotional resources). The Five Ways to Wellbeing are to Connect, Be active, Take notice, Keep learning, and Give (Aked et al., 2008b) and these are outlined in Figure 1. As a framework for evaluating human wellbeing, The Five Ways to Wellbeing have featured in several publications relating to human wellbeing and nature connectivity, including peer-reviewed research papers (Chiumento et al., 2018) and mainstream psychology publications (Harkness, 2019). And they have also been used within research, methodologies designed to measure good human wellbeing and improvements to quality of life, across numerous other disciplines in different parts of the world (Mahoney-Davies et al., 2017; Mackay et al., 2019; Gillard et al., 2021; Coren et al., 2022). The principles of the Five Ways to Wellbeing have been endorsed by the UK's mental health charity, "Mind" (Mind, 2023) and are also widely advertised by the UK's National Health Service as part of its mental health provision (National Health Service, 2022). Therefore, the Five Ways to Wellbeing approach is clearly seen as a credible formula for helping to provide practical support and tools to improve both individual and societal quality of life.

This article considers the key concepts of the Five Ways to Wellbeing and the role of zoos in providing meaningful connection to nature, opportunities to engage and interact with other individuals in a positive and constructive manner, and ways of getting involved in pro-conservation activities and initiatives. Promoting a connection to nature is essential if green and blue prescribing (nature-based interventions and activities prescribed to restore positive mental states, National Health Service, 2022) is to be wholly effective. It is centered in the concepts of green / blue prescribing that can offer treatment for mental health disorders, such as anxiety and depression (Owens and Bunce, 2022; Irvine et al., 2023) and that zoos could get involved with. This is the first time (to the authors' knowledge) that zoos as potential sites to embed the Five Ways to Wellbeing has been explored. A literature search, conducted in June 2023 on Google Scholar[1] and on Web of Science[2] for the terms "Five Ways / Five Steps to Wellbeing zoo," "Five Ways / Five Steps to Wellbeing aquarium," "Five Ways / Five Steps to Wellbeing nature" revealed no articles to have employed this method to date in the context of zoo operations and aims. Therefore, our concept paper reviews the operational nature of zoos and their aims, in terms of each of the Five Ways to illustrate the potential for this approach to future investigation and research application. We provide examples of how zoos can engage with each one of the Fives Ways to Wellbeing "actions" (Connect, Be active, Take notice, Keep learning, Give) to maximize their positive impacts on human wellbeing and planetary health both locally and globally. We have explored the framework of the Five Ways to Wellbeing to show how the activities that zoos provide and promote fit within the ideals and aims of the Five Ways to Wellbeing regarding improvements to human quality of life.

2. Connect

Zoos provide spaces that enable people to connect; both with each other and with the natural environment. A key element of the Five Ways to Wellbeing is the building and maintenance of positive relationships with others as a crucial element for long-term well-being. In the zoo, connecting with family, friends, colleagues, and the wider community is possible and can provide feelings of belonging, support, and purpose. Zoo visits foster a sense of interest in nature, facilitate social support, and spark positive discussion on the animals that visitors interact with Clayton et al. (2009) and Clayton et al. (2014). As being connected fosters an individual's sense of value and enhances social interactions (Martino et al., 2017), positive impacts on mental health and physical health become realized. Across the world, there are estimates that over 700 million people may visit a zoo annually (Gusset and Dick, 2011). By connecting individuals together as well as connecting people with nature, zoos can positively impact human health, and spread positive human Behavior change messages

1 scholar.google.com
2 webofscience.com

FIGURE 1
The Five Ways to Wellbeing as described by the New Economic Foundation with an example of how they integrate into a visit to a zoological collection.

more widely that can ultimately benefit planetary health too (Falk et al., 2007; Jensen et al., 2017; Godinez and Fernandez, 2019).

Use of various social media platforms and engagement with online audiences can foster interest and attention in a specific theme or idea (Derby, 2013). The use of multiple social media platforms is beneficial for zoos to connect with wider audiences, especially with people who may not consider visiting a zoo or who may not have an immediate, deeper interest in animals and the natural world. Using social media platforms as a bridge between any potential interest in animals (at the zoo) and then going to visit such animals can encourage nature connectivity during a physical visit to the zoo itself. In this scenario, engagement with a social media platform sparks the interest that results in a visit to see animals at the zoo. For example, by presenting information on conservation and biodiversity in a factually correct yet accessible and entertaining manner, e.g., on YouTube (Llewellyn and Rose, 2021) or on Facebook (Rose et al., 2018) zoos can build links to under-represented groups that may not have originally considered visiting an animal collection or natural space.

Zoos should also broaden their audiences to reduce any perception that they are just places for families and children to have a fun day out in Esson and Moss (2014) and Turley (2001). As an emphasis on being a playground for children can deter others from visiting zoos (Turley, 2001), wider consideration of how to connect with a more diverse array of audiences would provide more personal value to a zoo visit and give wider impact of any mental and physical health benefits. As zoo visits provide people with opportunities to develop emotional connections with non-human animals (Clayton et al., 2009; Howell et al., 2019), there is the chance to encourage pro-conservation and sustainability Behavior change post-zoo visit. By seeing animals in close proximity, zoos help foster a bond between the visitor and the natural wonder (Vining, 2003) and this emotional connection may help foster compassion for and interest in wildlife, biodiversity and the health of the planet. As many people visit zoos as a group (e.g., in a family setting), such a connection to nature can spread across generations and be a talking point or topic of discussion and dialog between these individuals in their social group (Figure 2).

In the UK, zoos employ approximately 3,000 full-time staff (Animal Careers Direct, 2023) and in the United States, AZA accredited zoos employ 198,000 people (Marcy, 2021). Not only does this represent vast opportunity for connection, both AZA and BIAZA (and many zoo member and accreditation organizations globally) host annual conferences and have active working groups offering further, wider connectivity to like-minded people who share an interest in animals. The sharing of joint goals like achieving husbandry development and striving for improved animal welfare, therefore affords a sense of camaraderie and togetherness. Those staff who work directly with animals can also participate in stable, strong attachments with the animals in their care. With companion animals, such

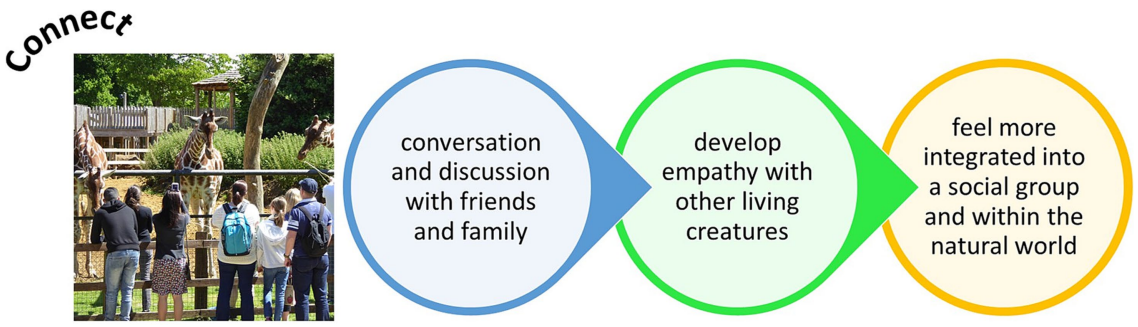

FIGURE 2
Ultimate benefits of being connected at the zoo and on a zoo visit.

attachments are considered a positive human-animal interaction that is important for both good animal welfare and positive human wellbeing (Walsh, 2009). Melfi et al. (2022) found that zookeepers did form such attachments to animal in their care, although not as strongly as with their own companion (pet) animals. This research identified that female zookeepers were significantly more attached to zoo animals than male zookeepers and thus there is the potential for all zookeepers but especially females to connect with the animals in their care. Even those whose work does not directly involve animals have daily opportunities to interact with animals as they journey around the zoo throughout the working day. Thus, zoo staff have many opportunities for connectivity with human and non-human animals alike.

Zoos need to consider animal welfare states and how these are upheld and promoted to visitors (Sayers, 2020), especially when connecting visitors with nature. Promoting good animal welfare is likely to leave a lasting positive impression on zoo visitors as research has identified that when zoo visitors view abnormal Behaviors (e.g., stereotypic pacing), they leave with a poorer impression of the zoo overall (Miller, 2012). Negative impressions of captive wildlife can be caused by a visitor's experiences of poor animal management (Woods, 2002), thus detracting from the zoo's value and its ability to connect more deeply with the audiences that visit. Likewise, the behavior of visitors themselves can disturb the animals themselves and create a negative atmosphere at the zoo (Collins et al., 2023), preventing others' attempts at connecting with nature more widely, or animals specifically, in the zoo. Consequently, zoos need to actively manage visitor Behavior, engaging with them to eliminate negative actions that compromise animal welfare and the experiences of other visitors who wish to fully connect with nature during their time in the zoo's living collection.

3. Be active

Any visit to a zoo or aquarium involves activity. Engaging in regular physical activity is beneficial for physical health and improves mental well-being (Warburton et al., 2006). And physical activity that is outdoors and embedded in nature alleviates stress and boosts quality of life during challenging periods of living (Egerer et al., 2022). Zoos can capitalize on such physical activity by outreach events and programs that can provide multiple opportunities for physical exercise, the broadening of social connections and chance to do or learn new things. Opportunities for engagement that encourage activity can include physical exercise, such as walking around exhibits and between enclosures, to engagement with educational activities that may involve creating, making, doing, or crafting (Figure 3). Walking tours and guided experiences also increase opportunities for physical activity around the zoo. These events are documented as being particularly effective at enhancing connectivity with nature from student groups (Kleespies et al., 2020) to middle-aged adults (Kleespies et al., 2022) and provide a way of promoting the intrinsic value of nature to urbanized audiences that may appear removed from biodiversity (de Lima, 2016). When an audience starts a tour with low nature connectivity, the event appears to be most effective at improving and increasing the individual's sense of value of nature (Kleespies et al., 2020). Given the staple of guided tours around zoos, this form of physical activity, coupled with the potential for large influences in positive connections to nature, would be something for zoos to capitalize on and promote more widely.

Participation in guided tours with other visitors could develop new social bonds and a sense of connection with other likeminded individuals that have similar interests and passions. These events involve activity (walking around the zoo itself) but also could encourage activity away from the zoo, and opportunities to explore other green or blue spaces that the visitor learns about during the visit. For example, zoos may manage a nature reserve at a separate location; if these nature reserves are highlighted to participants on a tour, a new venue for physical activity is made available for people to potentially engage with. Guided tours increase participants knowledge and education on a specific topic (Whitehouse-Tedd et al., 2022) and as such, could be used to present other opportunities for activity that leads to increased connection with nature both at and away from the zoo. Such guided tours may be particularly important for people who visit a zoo alone to give a chance to strike up conversation with others around them and to therefore broaden their own social environment. Zoos provide multiple topics of conservation and moving between enclosures provides a variety of sensory experiences that can be discussed, explained, and explored. Opportunities for this activity could themed for a specific audience to encourage uptake on a tailored activity with key aims for that demographic.

Involvement in "keeper for a day" schemes or other opportunities to work with animals, such as volunteer programs, are also beneficial for improving visitors expectations and engagement with nature (Meadows, 2011; Ferguson and Litchfield, 2018). Such experiences add more

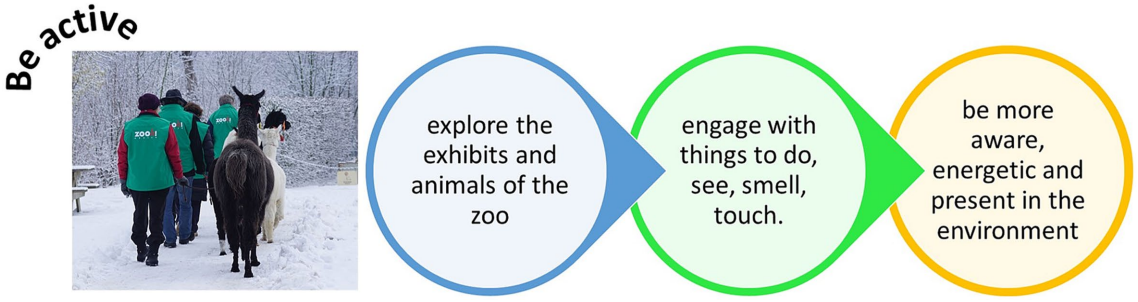

FIGURE 3
Being active at the zoo to improve physical health and how to connect with nature.

opportunities to complete physical activity, to bond with others and to experience nature close-up. Whilst caring for zoo animals is physically demanding work, zoos should consider developing volunteer programs that are accessible (where logistically possible) to all sections of society and particularly consider outreach to less mobile individuals that would still benefit from close encounters with nature. Examples of widening participation in such experiences are found within the industry (Sydney Zoo, 2021; Blackpool Zoo, 2023) and this highlights the evolution of how zoos are encouraging the widest spectrum of society to come and engage with their messaging, key objectives, and with their living collections. As direct encounters with the animals themselves also involve physical activity, so this helps foster a connection with particular species in the zoo, and with nature more broadly.

Of course, zoos employ real keepers and a host of other staff who engage in physically demanding work as they clean animal enclosures, prepare animal diets, build or repair infrastructure and generally walk the many paths at the zoo as they visit different areas of the zoo as part of their work. Here another opportunity presents for zoos to evidence humans being active and fulfilling the second of the Five Ways for Wellbeing. In the sparse research into zookeeper opinions of their role and work environment, keepers acknowledge the 'hard work' their job entails; they describe 'a calling' and a need to work with animals, the importance and meaning of their role, but verbalize the sacrifice such physically and emotionally demanding work requires in terms of financial limitations, vigilance and the burdens of responsibility (Bunderson and Thompson, 2009). Thus, a need to further explore zookeeper wellbeing transpires as these are active people, engaging enthusiastically with the sensory riches that their site of employment affords yet such wellbeing benefits are potentially at risk from the burdens of responsibility zookeepers report experiencing.

4. Take notice

Watching and experiencing the presence of zoo animals can encourage visitors to take notice of important messages (Grajal et al., 2017; Moss and Pavitt, 2019) that could enable personal growth and development. For example, by learning about previously unknown facts, concepts, and theories, or by developing pro-conservation Behavior and engaging with tools to become more sustainable. An integrated approach of signage and other forms of communication and interpretation (such as interactive engagement with social media platforms) has been shown as particularly effective at crystallizing key biodiversity messages to zoo visitors (Pearson et al., 2014). Zoos are places where people come to have encounters with other species (Rice et al., 2021a) and by seeking out such close encounters, visitors are taking more notice of the natural world and are being more connected to aspects of nature. By encouraging visitors to take notice, of the animals in the zoo and in a wider context, and of the visitor's own learning and development, zoos can help people to reconnect with the wider world around them (Figure 4).

There is multiple evidence of how zoos contribute more widely to scientific outputs that can benefit wider society. Publication and dissemination of empirical science in the popular press and across media channels make scientific outputs more relevant and relatable to general, non-technical audiences (Farinella, 2018). Across zoo membership and accreditation organizations, zoo and aquarium research is answering new questions and providing insightful and impactful information on a wide range of subjects (Loh et al., 2018; Hosey et al., 2019; Hvilsom et al., 2020). Scientific outputs from zoos improve our theoretical and applied knowledge of the natural world (Conde et al., 2019; Rose et al., 2019) and such information can be presented in an accessible and engaging way to visitors to encourage uptake and memory of important messaging (e.g., around a species' ecology or conservation or adaptations).

Zoos also engage in sensory experiences with their visitors that encourage people to take notice of their environment in different or extraordinary ways. For example, sound walks where visitors are encouraged to experience the zoo by listening to their environment and not through sight (Rice et al., 2021b). Sound walks are unlikely to be fully accessible to visitors with hearing impairments, but these activities can open up the zoo's environment in new ways for people with other sensory disabilities, e.g., those that are visually impaired. By encouraging visitors to engage with different senses, a new perspective on the zoo, its animals and what it means to be in nature can develop.

Zoos can also offer mindfulness programs and activities centered around this mental health paradigm. Mindfulness refers to *"a moment-by-moment awareness of our thoughts, feelings, bodily sensations, and surrounding environment, through a gentle, nurturing lens"* (University of California Berkeley, 2023). And anyone practicing mindfulness is required to accept, and not judge, their current thoughts and feelings; to accept who they are in that current space and time. Mindfulness concepts can be built into wildlife encounters and experiences to promote a deeper connection with the natural environment and to enhance learning and engagement (Woods and Moscardo, 2003). The sound walks, as mentioned above, can encourage "acoustic mindfulness"

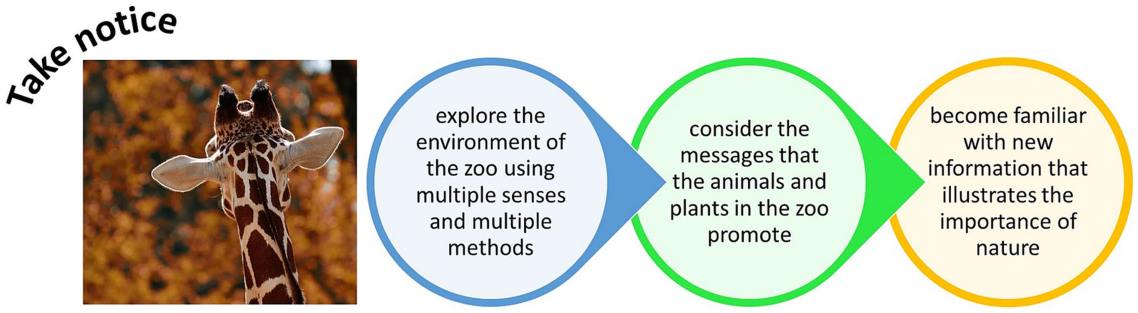

FIGURE 4
Taking notice at the zoo to learn about nature in new ways and feel more connected to the natural world.

and reflection on the lives of the non-human animals at the zoo (Rice et al., 2021b), therefore deepening participant's connection with nature on a different sensory level. Visitors on mindfulness walks at the zoo can be encouraged to pay close attention to their surroundings, and notice the colors, shapes, sizes and activity patterns of the animals, and how the animal fits into its environment. Some zoos provide a guide and instructions on how to practice mindfulness on a zoo visit (Meek, 2016; Chester Zoo, 2023) including ideas for things to do (what to watch and experience), what to not do (e.g., avoid needing to photograph everything that can be seen or viewing the world via a mobile phone screen), and how to engage multiple senses.

Mindfulness is not simply a statement or singular reflection in time and space, it is a practice that is developed and fine-tuned with repetition and application; there is a level of dedication involved in focusing your thoughts on to your current state of being. Mindfulness refers to "observation without criticism" (Williams and Penman, 2011) allowing negative thoughts to be noticed before they have chance to fully infiltrate a person's psychology. Therefore, zoos should work to embed mindfulness practice into a visit, offering opportunities for focused thought and the quiet reflective spaces needed to achieve a truly mindful state. Other forms of mindfulness out in nature, such as "forest therapy" result in numerous physical and psychological benefits to participants (Han et al., 2016; Rosa et al., 2021). Zoos should capitalize on such research to build and promote their own mindfulness programs, especially as many zoos are wooded and could participate in similar forest therapy style events. If zoos can provide such opportunities, both visitors and staff may reap the benefits, including reduced anxiety and depression (Khoury et al., 2015), lower pain scores (Reiner et al., 2013), and improved immunity (Davidson et al., 2003). For visitors, this increases the likelihood of returning to the zoo and valuing the zoo's work. In turn, this creates longevity in the zoo's appeal and its influence. For zookeepers, mindfulness events afford opportunities to deal with the burdens of responsibility that zookeeping entails. Zookeepers need time to reflect and focus their thoughts, allowing them to preserve their own wellbeing and better notice when the wellbeing of animals in their care changes and intervention is required. As such, as human wellbeing improved, so does animal wellbeing also improve.

5. Keep learning

An integral aim of the modern zoo is education (Kleiman, 1985), which adds value to the zoo's living collection, its operations and impacts on society more widely (Greenwell et al., 2023). Zoos have well planned and structured educational offerings for pre-school, school, college, and university-level groups, and provide a wealth of informal educational materials and activities for general visitors too. The importance of zoo education programs is well reviewed and often evaluated to ensure efficacy (WAZA, 2023; EAZA, 2023b). Formal education sessions and informal educational activities can develop the participants' connection with nature (Packer and Ballantyne, 2010; Kleespies et al., 2020, 2022). Zoo visitors are receptive to information on wider global issues, e.g., implications of climate change (Taylor and Duram, 2021), and as zoos can promote lifelong learning (Luebke et al., 2012), visits to the zoo can improve awareness and understanding of such global issues to promote positive Behavior change that benefits the quality of life of multiple individuals. As visitor attitudes and perceptions are influenced by the visual messages that they receive as they move through the zoo (Reade and Waran, 1996), zoos should consider the visitor's journey through the zoo and how opportunities for learning are presented and made available at different enclosures and exhibits. Learning stations and interpretation also needs to consider the demographic at the zoo and perhaps ensure that adult visitors are catered for, as well as children.

Further development of how zoos use social media to provide information to their visitors should be undertaken to maximize integration of real world and online experiences. For example, research on use of social (e.g., a social media platform) and mobile (e.g., personal mobile phones) technologies as part of a museum visit revealed wider engagement of participants, provoked multiple opportunities for social exchange and did not interfere with real time engagement with the physical artifacts on display (Charitonos et al., 2012). These authors also note the importance of integrating social and mobile technologies into educational visits to encourage engagement with overlooked or disadvantaged groups of people.

Many zoos offer educational talks or presentations by zoo staff. Attending these sessions can provide valuable insights into animal Behavior, conservation actions, and the importance of biodiversity to human and planetary health (Figure 5). Live animal shows can be successful in connecting visitors to nature if they display the animal's adaptations and natural Behavioral traits (Povey and Rios, 2002; Spooner et al., 2021), therefore informal education that connects the audience to the animal and its environment is achieved through the display of the animal's evolutionary characteristics. Linking evolution to ecology, and then to threats and challenges that populations face (e.g., habitat loss and population reductions due to

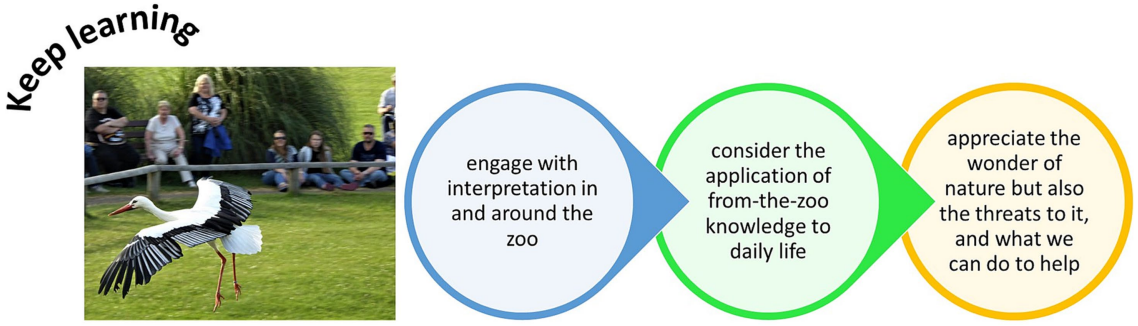

FIGURE 5
Opportunities to keep learning by visiting a zoo, interacting with signage and with animal displays or encounters, and taking away key information to promote positive human Behavior change.

human activities) may allow an audience to see just why animals are threatened, because they possess specific traits and adaptations for specific environments that humans are destroying. Such sessions can grow each individual's knowledge of conservation issues (Spooner et al., 2021) and, if such information is included in the demonstration, could become tangible tools that encourage audiences to be more sustainable and planetary friendly in daily life (Mellish et al., 2017).

Such sessions may also provide opportunities for social connections with others, and the chance to build links at the zoo that may result in longer term volunteering roles or similar. Using virtual reality (VR) to augment keeper presentations and educational sessions can bring the otherwise unseen day-to-day care of the zoo's animals to the visitor's attention (Carter et al., 2020). Employing novel technologies, such as VR, alongside of social media platforms or app-based methods could inspire deeper and more impactful learning at the zoo to a wider demographic. Visitors respond positively to the presence of VR alongside of also experiencing the live animal in the same space (Carter et al., 2020). Such integrated approaches, of presenting the animal in an enclosure, and of using other forms of technology to reduce distance between the animal and the visitor, could be employed (and evaluated) to see how well connection to nature is advanced, if information presented about the animal is retained for longer, and if visitors feel a deeper bond with the animal they are viewing.

When zoo staff prepare such formal and informal, active and passive learning opportunities, so to are they also experiences their own learning opportunities. Welfare, Behavior, conservation, research and animal care staff at the zoo must embed the latest scientific literature into practice, and therefore must engage with continuous professional development opportunities to ensure they can follow an evidence-based approach. Building mutually respectful and trusting collaborations with academic departments can enable access to scientific research papers and further opportunities for professional development (Fernandez and Timberlake, 2008; Schulz et al., 2022). Regional zoo associations also run CPD training events from across a broad spectrum of topics from general zoo governance to species-specific husbandry (ABWAK, 2023; BIAZA, 2023b). Zoo staff report valuing such learning opportunities but do not always feel supported to seek out or attend conferences and events (Bacon et al., 2021). Supporting zoo staff to attend such events is therefore essential because it allows learning to occur and further enhances staff social and professional connections across and within organizations. It also adds value to the diverse job roles at the zoo and allows staff opportunities for positive reflection on their own self-development.

6. Give

Being at the zoo also encourages people to give back to try and help the natural world in some capacity. Giving does not mean material items or financial donations, although (where this is financially able and fiscally responsible) donating money to a charity does improve mood (Geng et al., 2021). Those working at the zoo already give back, sometimes with limited financial reward or opportunity for career progression, as zookeepers report self-sacrifice while seeing they have a moral obligation to provide good welfare opportunities for the animals in their care (Bunderson and Thompson, 2009). The public too have opportunities to give. Volunteering time is a form of giving that zoos readily facilitate (BIAZA, 2023c). Research suggests that acts of giving help improve mental wellbeing by creating positive feelings and a sense of reward, promoting feelings of purpose and self-worth, and helping to establish connections with others in the community (Lum and Lightfoot, 2005; Rochester, 2006; Vannier et al., 2021). Although not all research agrees with ideas that volunteering always brings wellbeing benefits (Whillans et al., 2016), study of zoo volunteers shows a profoundly positive response to the work that they conduct (Fraser et al., 2009). Volunteers that are trained, and therefore feel invested in, can report the largest positive outputs from their work (Smith et al., 2018). Therefore, to ensure positive mental health outcomes, volunteer programs should align (as best possible) with the volunteer's expectations, wants and needs from the work and any pre-existing skills and expertise. As well managed volunteer programs, that value and invest in their volunteers, can increase uptake of pro-environmental and pro-conservation Behaviors (Bixler et al., 2014), zoos can improve connection to nature and provide fulfilling and meaningful community engagement opportunities *via* their application of volunteers. Although the zoo and its operations will benefit from the presence of volunteers, it is essential that zoos see volunteers as more than this (Smith et al., 2018), and actively provide programs for development and learning alongside of the duties required of the voluntary position.

Volunteering increases human and social capital (Forbes and Zampelli, 2014). Human capital can be defined as the *"knowledge, skills, and health that people invest in and accumulate throughout their*

lives" (The World Bank, 2022), and the extent of this capital helps realize an individual's potential productivity to society. Social capital is harder to define but considers the social relations that individuals can form that have productive benefits (Institute for Social Capital, 2023), for example opportunities to form, develop and invest in professional and personal relationships that have meaning to the individuals involved. Zoos should consider human and social capital in terms of benefits to the volunteer and to the organization, and to nature conservation and planetary health more widely, when designing and implementing volunteer schemes. The volunteer giving time to the zoo, and the zoo giving resources and opportunities to the volunteer strengthens the overall impact of this relationship on the zoo's education, engagement and conservation aims, and can boost the positive quality of life outcomes experienced by the individual who is volunteering (Figure 6). This of course is also the case for those employed at the zoo and who go above and beyond to uphold and evidence industry values, the zoo's mission statement and public expectation relating to animal care. Further research into the personal goals and aspirations of volunteers, their motivations behind taking on the role, what they have gained from it and why they feel this is important should be conducted more widely. Such research would provide evidence for how to develop volunteers, maintain their interest and enthusiasm, and ensure they feel valued and appreciated.

7. Discussion

In this article we have shown that working at or visiting a zoo enables connection with biodiversity and positive feelings of wellbeing. We suggest that zoos can consider a Five Ways to Wellbeing approach when discussing and implementing their living collection plans, designing and crafting visions, mission statements and operational strategies, and embedding opportunities for formal and informal learning for all visitors, staff and volunteers. Each of the Five Ways to Wellbeing are not mutually exclusive. Engagement with one leads to involvement in activities that fulfill many of the others. The multi-dimensional nature of a zoo visit (from seeing the animals, to engaging with people, to exploring a new environment, to the travel to and around the facility, to learning new information and developing ways of using such information) provides a unique way for visitors to become immersed in an environment that can positively impact on physical and mental health. Zoos need to ensure that the environment presented to visitors is a positive one. Animals need to be healthy, behaving in a species-typical, ecologically relevant manner, and all signage, interpretation and messaging needs to be clear and transparent. Zoos educational and conservation messages can be diluted if animals are behaving abnormally and if visitors leave with a poor view of how seriously the zoo views animal welfare. Therefore, developing the zoo as tool to improve mental health and human wellbeing goes hand-in-hand with developments to animal husbandry and management. The zoo must keep abreast of scientific evidence for best practice husbandry (Rose, 2018) and continue to enhance and evolve enclosures and exhibit design so that animal welfare is also good and all living beings maintained in the zoo's collection have an opportunity to experience "a good life" (Green and Mellor, 2011).

Monitoring of physical and psychological outputs during a zoo visit show that the activity of walking around a zoo reduces blood pressure, increases step rates and improve positive outlooks on life (Sakagami and Ohta, 2010). Encouraging activity by taking visitors on a journey around different enclosures and exhibits therefore has multiple health and wellbeing benefits, as well as encouraging people to feel more relaxed and, therefore, potentially keener to be in the moment and connect to nature. The New Economics Forum has evidenced that those who have strong social relationships, are physically active and continue to be involved in learning experience improvements to wellbeing and physical health (Aked et al., 2008a), as social bonds, an active lifestyle and opportunities for learning are all important influencers of health and wellbeing. If zoos are able to identify wellbeing needs in their local communities and target reduced price visitation accordingly, the Five Ways to Wellbeing could be more readily realized for more people who are disconnected from nature. Using the zoo as a way to exercise, whilst learning for example, may open up further possibilities to engage with different demographics.

Being active in the zoo can help people to "move their mood" (Tonkin and Whitaker, 2021) and spending time on leisure activities at the zoo (with family and friends) can instigate conservations, discussions and dialog to help people feel more connected. Research has identified that spending time in immersive zoological exhibits improve the mood of visitors (with self-reported feelings of happiness increasing) and reduces stress (Coolman et al., 2020). Zoos should build on these positive findings by providing maps, trials or tools that relate to the Five Ways to Wellbeing to easily share this concept with zoo visitors. Not all mental health challenges are discussed or visible, and a lowkey approach to improving mood and emotion may help individuals, when they leave the zoo, make changes to their daily lives that will improve their quality of life and reduce anxiety.

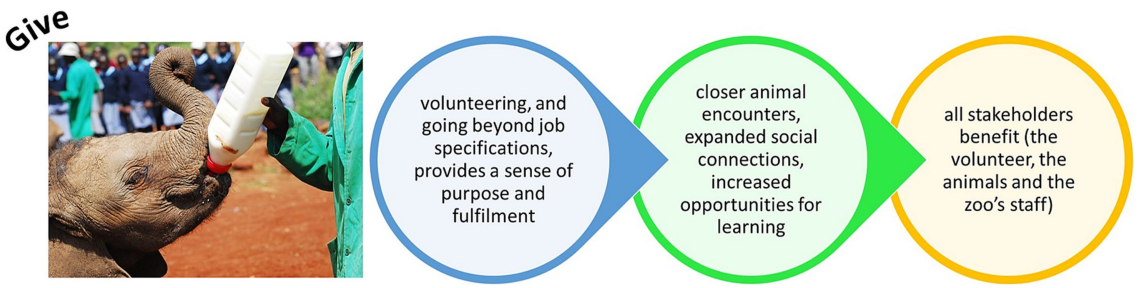

FIGURE 6
Providing opportunities for people to give back at the zoo can increase social capital (i.e., investment in friendships and in the activities of the organization) and increase human capital (i.e., personal knowledge and skills).

For those immersed in these environments as their place of work, there are connection benefits too, particularly for animal care staff. Their roles require undertaking physically demanding work yet their willingness to "give back" beyond their job description resonates as they see the value in their efforts to animal welfare and conservation outcomes. Compassion fatigue is a genuine risk to animal care staff (Figley and Roop, 2006) as the toll of seeing animals failing to thrive can manifest into acquiescence. The relevance of good animal welfare here is paramount – seeing animals thrive brings a sense of proud fulfillment and pride in one's job. This enhances happiness and creates opportunities to connect with other staff to share successes and good practice, and consequential scope for mindful happiness. Zoos should value their staff and sufficiently support their needs, both personal and professional, while prioritizing animal welfare to evidence the Five Ways to Wellbeing in their extensive workforce.

Key challenges that zoos face to provide a more egalitarian "Five Ways to Wellbeing" experience centre around entry costs and accessibility. Collaboration between institutions when concerning supplies, logistics and procurement, could reduce operating costs (Baptista et al., 2021) and therefore zoos may be able to make reductions to ticket prices for low income groups or for sections of society that may have less disposable income to expend on entry tickets. Corporate sponsorship of reduced ticket entry could widen access to the zoo, and zoos should continue to build relationships with industry partners that could help subsidize ticket costs for key demographics that zoos wish to engage with. Zoos should consider the impact of ticket pricing as a potential barrier to engagement with their work, and engage with external social initiatives, widening participation schemes and philanthropy within their local community to attract audiences that may be unable or unwilling to visit. For example, the "Generation Wild" initiative at the Wildfowl & Wetlands Trust (WWT) aims to break down barriers to access to nature, and provides free site entry plus follow-up learning opportunities to build pro-nature, pro-conservation attitudes and Behavior change in adults and children alike (WWT, 2023). Increasing the use of different tools for communication could provide zoos with a way of reaching a wider societal demographic with associated wider societal impacts. Multiple layers of interpretation have been shown as the most effective way of instilling memorable and relatable messaging when experiencing a zoo exhibit (Weiler and Smith, 2009). Therefore, combining different media and formats of messaging could help zoos extend the reach of their key educational outputs and encourage more people to feel connected to nature, as well as encouraging the Keep Learning aspect of the Five Ways to Wellbeing.

Zoos also need to consider how disconnected visitors, volunteers and staff may initially be from nature. Oh et al. (2021) demonstrate that spending a longer in nature than usual can be more stressful or anxiety-inducing if the person's baseline connectivity to nature was weak to begin with. Therefore, zoos need to be mindful of the background of individuals who they attempt to engage with, their prior experiences of the natural world and how they perceive any relationship with nature, before embarking on nature connectivity programs or events. In this article, we have provided an overview of the activities of the modern zoo that support these Five Ways to Wellbeing, in the hope that others will take these concepts, apply and test them to encourage new and effective ways of human engagement with the zoo's mission and objectives.

Nature-based interventions within the zoo can be of benefit for specific groups of people. For example, individuals with disabilities are less likely to spend time in nature than able-bodied people (Sahlin et al., 2019). Providing nature based interventions for disabled people and their carers has positive educational outputs and improved caretakers enthusiasm for their profession by facilitating new ways of managing stress and providing tools to improve mood (Sahlin et al., 2019). Zoos should work on their outreach programs with under-represented groups, and those with limited access to nature, to ensure the zoo's green and blue spaces, and the animal collection, are accessible to all those who may benefit from being immersed in a natural setting. Investing in such initiatives and objectives today means ensuring visitor footfall and recruitment of a sustainable workforce in the future.

Zoos should continue to research the potential of their living collections as being beneficial to nature connectivity and as a tool to improve emotions and mood. Research identifies that whilst there can be common, positive findings on how observing and interacting with animals improves human wellbeing (Sahrmann et al., 2016; Gee et al., 2019), methodological limitations, biases in experimental design and lack of repeatability can reduce generalisability of research findings (Clements et al., 2019). Cross institutional research, using standardized methods and pre-registering projects to encourage scrutiny prior to data collection may help to generate more robust conclusions that can help decipher exactly why being in nature, or being near animals, is beneficial to human wellbeing.

Zoos can increase connection to nature by considering the situation that experiences take place in. Research on situational interest, i.e., the specific features of a place, location or artifact (Schiefele, 2009), can provide zoos with information on how to present learning opportunities to increase connection with nature. A zoo's landscape ecology, it's "zooscape" (Bisgrove, 2022), can promote connection to nature whilst explain the ecological and social importance of habitats and green/blue spaces. Bonderup Dohn (2011) found that school children who were presented with learning activities within an aquarium responded positively to the experience because of the setting. This research identified that the children's social involvement, the hands-on element of the activity, the activity being a surprise and novel, and the aspect of knowledge acquisition as the main outcome, to be key triggers of interest. These findings are useful for zoos to consider when planning and designing both formal and informal education sessions and when they wish to foster the interest of their visitors in important, fundamental topics (e.g., biodiversity conservation).

Whilst zoos are working hard to expand their wider influences and extend their role in society, there are still areas of publication output and scientific enquiry that can be worked on Rose et al. (2019). For example, Anzai et al. (2022) shows that not all zoos can have a focus on scientific research and not all research enquiry focuses on the key aims of the modern zoo. Therefore, zoos should continue to increase collaboration and the development of relationships across their own industry and externally too (e.g., with academic departments at universities) to enable all important aspects of their operations to be evidence based. Ultimately, zoos and aquariums need to place a greater emphasis on animal welfare and on human wellbeing as part of their core aims, operational outputs and influence over human populations (their visitors, staff and stakeholders). As examined by Rose and Riley (2022), cementing Wellbeing as a key aim of the modern zoo provides clear evidence to all invested parties that zoos fundamentally care about animal welfare and human wellbeing because they are working to promote, protect and preserve positive aspects of mental health.

Research has identified that people who care about threats to the natural world are more likely to spend time at the zoo and view

the zoo's work as positive for nature conservation and as a way of encouraging planetary friendly Behavior change (Taylor and Duram, 2021). However, there are many people who may not consider visiting the zoo (as a way of interacting with green and blue spaces) and so zoos should focus some of their efforts and resources on reaching groups of people that are less regular visitors or who never visit. For some, zoos can be controversial institutions whose aims appear contradictory (Wickins-Dražilová, 2006; Carr and Cohen, 2011; Maynard, 2018). Therefore, the idea of connecting with the natural world in the unnatural setting of zoo's enclosures and exhibits may appear incompatible. Zoos should therefore promote and explain examples of Behavioral consistency between wild individual and those under human care. For example, parity of vigilance activity in meerkats that, even after many generations in captivity, still perform key wild-type Behaviors (Huels and Stoeger, 2022). This would demonstrate the care that zoos place in their husbandry and management to ensure that species in the living collections remain a true representation of nature. Zoos should also consider the language they use and how they promote themselves. For example, using the term "habitat" for an animal's enclosure (Bruno et al., 2023) could be seen as disingenuous; a habitat is a biological system, where a species interacts with a myriad of biotic and abiotic interactions (European Environment Agency, 2023). A zoo's managed environment controls these interactions, and therefore explaining to visitors how specific aspects and resources of a habitat are replicated within an enclosure may be a more honest way of educating visitors on species' ecology. There is clearly a role for zoos in the protection, promotion and conservation of species that is promoted *via* public education (Whitehead, 1995; McCubbin, 2022). Getting the messaging right, being honest and transparent, and accessible, to encourage wider buy-in of such roles will enhance the relevance of the zoo to a wider demographic.

This article has explored the concept of the Five Ways to Wellbeing regarding the activities and operations of zoos that could be directly co-opted to promote human wellbeing and connection to nature. We have reviewed the scientific literature and practical examples of zoos' works to demonstrate how the aims and goals of such activities can improve human health and wellbeing, promote access to green/blue spaces and support more opportunities for nature connectivity. Due to the nature of a review paper, we are unable to evaluate or analyze the timescale, logistical considerations, financial requirements, or personnel needs of successfully embedding the Five Ways to Wellbeing into the work of the modern zoo. Empirical information is required to understand how well our suggested Five Ways to Wellbeing concepts and approaches would fare in practice. Further research into the design of a Five Ways to Wellbeing initiative or activity, followed by its implementation, and eventual evaluation and assessment of measurable impact is required to fully evidence the relevance of this approach to the positive outcomes of visiting a zoo and engaging with its living collection and green/blue spaces.

8. Conclusion

This article has reviewed how a Government-instigated initiative that aims to improve human mental health and quality of life could be useful for zoological collections to consider as a way of working to enhance the wellbeing of their communities and improve connection with nature. Our article shows how the key concepts of the Five Ways to Wellbeing can form a framework for zoos to further engage with their human audiences. Each of the Five Ways to Wellbeing is relevant to the work that zoological collections do for their staff, visitors, and the wider communities around them. We have shown that zoos contain many useful and relevant exhibits (e.g., animals within their enclosures), programs (e.g., educational activities and public talks), and resources (e.g., open green spaces, planting, biological artifacts) that together provide multiple opportunities to apply the ideas of Five Ways to Wellbeing. The zoo's most important resources is its living collection of plants and animals; by tailoring the use of the living collection to improve engagement with the natural world and to better connect their workforce and visitors to nature, zoos are not only able to advance wellbeing of their human stakeholders but also add more value to that already intrinsic within the living collection itself.

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The influence path of community green exposure index on activity behavior under multi-dimensional spatial perception

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The purpose of this research is to reveal the internal relationship among community green space, space perception, and activity behavior response to supplement the lack of research results on the binary relationship between green space and behavior. Nine residential community green spaces and 398 residents were selected as the research objects. Thematic clustering and factor identification were used to determine the spatial dimensions of community green space that residents were concerned about. The analysis of the green exposure index, spatial perception evaluation, and activity behavior survey were combined to determine the influence of the green exposure index on spatial perception and activity behavior and its internal correlation path. According to research data, the community green view index (GVI) and normalized difference vegetation index (NDVI) negatively affected the perception factor, while the perception factor positively affected the activity frequency. The SEM model shows that the green exposure index stimulated activity behavior through the intermediate effect of the internal perception path of perceived landscape quality, perceived workability, and perceived accessibility. Spatial perception as the basis of the instantaneous emotional reaction process may affect people's choices for activities but be unable to extend the duration of the activities. The internal association among community green space, spatial perception, and physical activity behavior develops on the basis of spatial patterns at certain scales. This study provides a theoretical basis for understanding the spatial experience and residents' behavioral needs, evaluating the quality of urban green space scientifically, and promoting the optimization of community green space structure.

KEYWORDS

spatial perception, activity behavior, community green space, normalized difference vegetation index, green view index

1. Introduction

Human beings, going through evolution over millions of years, have formed a psychological mechanism for adapting to the natural environment. The physical attributes of the natural environment lead to aesthetic preferences and emotional responses through perceptual filters, which then affect psychological emotions and cognition (1, 2), relieve mental fatigue, and balance physiological functions, finally contributing to the stimulation of behaviors or functions so as to promote health and survival adaptation (3, 4). As a sensory interaction process to obtain information about the natural environment, "perception" is the

psychological foundation as well as the determinant of individual decision-making across time and space (5). As the representative subject of urban natural environment, urban green space carries four potential ways to improve the ecological environment, restore physiological capacity, promote physical activity, and improve social interaction with public health (6). Empirical research has found that the complexity and multi-dimensional nature of urban green spaces may lead to different psychological reactions and behavioral stimuli, which in turn affect physical activity levels (7, 8). Therefore, compared with the objective geographical space characteristics, the subjective perceptual attributes of urban green space exert much more empirical value for residents to participate in outdoor activities and maintain their physical health.

Green space exposure assessment is generally considered a scientific evaluation method for studying urban green space and population health. It consists of two major evaluation indices, which are the two-dimensional ground greening evaluation index normalized difference vegetation index (NDVI) and the facade space greening evaluation index green view index (GVI) (9). By capturing the growth potential and increment of ground vegetation through satellite images, NDVI can reflect the density of above-ground green vegetation in a relatively accurate manner, and it is widely applied to the classification of urban land cover types, the assessment of urban ecological environment quality, and the research on the relationship between urban green space and health (10, 11). GVI refers to the proportion of green parts in the field of vision (12), and it is regarded as an evaluation index to reveal the perception preference in human settlements and measure urban greening construction. In recent years, NDVI and GVI supplement each other in two different spatial dimensions (ground two-dimensional scene and street three-dimensional scene) so as to achieve a comprehensive evaluation of urban greening quality and green spatial perceived experience, thereby being regarded as two indicators most applicable to the empirical analysis of the relationship between urban green space and physical activity behavior as well as epidemiological health results (13).

Community green space in China as a type of urban green space is highly relied on by residents in daily life to provide a safer, accessible, and attractive environment in the neighborhood. However, it may cause less daily use and participation in physical activities for residents due to a series of problems such as unreasonable space planning, excessive greening, unscientific plant configuration, or poor maintenance and management (14). From a practical perspective, community green space was planned and designed to mainly meet the amenity value and ecological environment benefits, providing recreational places and satisfying space experience as the least prior functions. From the theoretical perspective, most relevant studies emphasize the binary relationship between green space and individual psychology (5), behavior, or health, ignoring the intermediate role of visual perception interaction between humans and the environment, and it is difficult to identify the characteristics of green space that residents truly prefer and experience comfort. However, some studies have pointed out that there are biopsychosocial pathways between community green space exposure and health, indicating that there are multiple relationships between green space and health or behavior. This study focused on the intermediate role of visual perception and proposed a hypothetical path of the green exposure index affecting activity behavior through spatial perception. A regression analysis and a structural equation model were used to reveal the effect of the green exposure index based on multidimensional perception of activity behavior and its internal relationship. It is hoped that this study can provide theoretical support for accurate community planning and decision-making as well as the creation of healthy community life circles.

2. Methodology

2.1. Study area and data

Investigation destinations are located on Haitangxi Street, Nan'an District, Chongqing, China. The research communities include nine residential communities (Figures 1, 2): Huilongwan community (HLW), Jiangnan Fenting community (JNFT), Luzhou Longcheng community (LZLC), Nanzhongyuan community (NZY), Xuefuyuan community (XFY), Sanheyuan community (SHY), Xinglongyuan community (XLY), Sigongli A community (SGLA), and Sigongli B community (SGLB). Housing properties include three types: commercial housing (CH), unit community (UC), and security housing (SH). The investigation was conducted in June with the best landscape effect and minimum external factors, and the whole process was conducted on cloudy days to avoid the potential impact of weather on personal subjective feelings. Older adults with no allergic history, aged 50–70 years, with certain thinking abilities as well as language skills, were chosen as respondents. To avoid the exclusion or avoidance of the respondents to the investigation process, structured interviews and questionnaire surveys were performed in the research community after random sampling in the main form of a team survey involving professional investigators, property management personnel, and undergraduate students.

2.2. Problem measurement and questionnaire design

To ensure the reliability, validity, and accuracy of the expression content of research variables, the research systematically reviewed the domestic and foreign literature, and then thematic cluster analysis was taken on green spatial perception variables at the neighborhood scale. Through pre-survey, three aspects of community residents were obtained: (1) the overall feeling of community green space and the experience value of site-specific information; (2) views and opinions on the role and management of green space; and (3) understanding of the function, use, and importance of green space. Through the collation of information, the most commonly used descriptive word by the residents and the space experience measuring variables most valuable for community green space were selected. Eight perception measuring items initially obtained were then used for exploratory factor analysis, and three perception factors with the highest degree of association were extracted. According to variable attributes, these three perception factors were named perceived

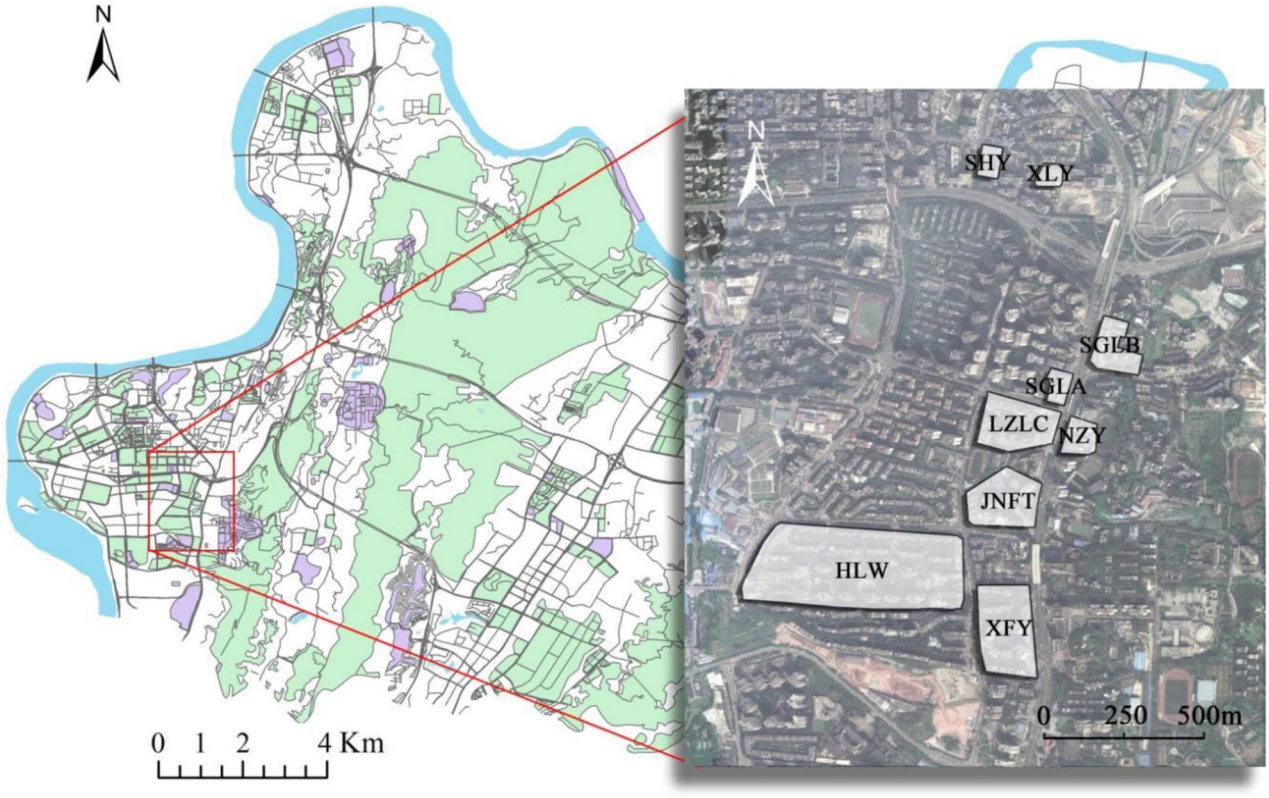

FIGURE 1
The bottom map is the administrative area of Nan'an District, Chongqing, where the research community is located. A zoom is made to highlight the spatial boundaries of the research community.

landscape quality (Q), perceived accessibility (A), and perceived workability (U), respectively (Table 1). Among them, Q included two measuring items, which were naturalness (Q1) and aesthetics (Q2); U included three measuring items, which were safety (A1), friendliness (A2), and connectivity (A3); and U included three measuring items, which were cleanliness (U1), facility integrity (U2), and functionality (U3). Each measuring item represented a measuring variable containing several measuring evaluation problems. Finally, a perception evaluation system was established, and a comprehensive perception evaluation of community green space was revealed from different perception dimensions.

The "community green spatial perception and activity behavior" questionnaire was designed, and three aspects were contained: (1) socio-demographic characteristics of the respondents; (2) community green spatial perception evaluation; and (3) green space activity evaluation of recreational physical activity behavior. The community green spatial perception evaluation in the questionnaire adopted the 5-grade Likert scoring system for the above-constructed evaluation system. This study mainly focused on outdoor physical exercise, which was one of the four major types of physical activity, excluding leisure time chatting or sedentary activities. The measuring items targeting recreational physical activity behavior in green space activity were identified as activity time (PT) and activity frequency (PF) of recreational physical activity, namely the outdoor physical exercise in an average week. The evaluation score was given according to the length and frequency of time, in which PT referred to the average use time of green space in each activity (PT $\leq$ 10 min, 1 score; 11–20 min, 2 scores; 21–30 min, 3 scores; and $\geq$30 min, 4 scores); PF referred to the number of times of green space activities in an average week (PF = 0, 1 score; 1–2, 2 scores; 3–6, 3 scores; 7–10, 4 scores; and over 10, 5 scores).

2.3. Determination of the green exposure index

Normalized difference vegetation index (NDVI): The satellite remote sensing image of the research community (precision: 10 × 10 m) was visually interpreted using the ArcMap 10.2 software, and information including the location, type, and area information of the green space boundaries, roads, and buildings in the research community was extracted. The remote sensing image went through spectral analysis using ENVI5.6, and the NDVI value of the research community was calculated by the ratio of the difference between the values of the near-infrared band and the visible red band and the sum of the values of these two bands (value range: 0–1).

Green view index (GVI): By using mobile GPS (Google Map App), equidistant sample points (30 m each) were set along the walking path of the main roads in the research community, and

FIGURE 2
Realistic pictures of the research community. **(A)** Huilongwan community (HLW); **(B)** Jiangnan Fenting community (JNFT); **(C)** Luzhou Longcheng community (LZLC); **(D)** Xuefuyuan community (XFY); **(E)** Nanzhongyuan community (NZY); **(F)** Sanheyuan community (SHY); **(G)** Xinglongyuan community (XLY); **(H)** Sigongli A community (SGLA); and **(I)** Sigongli B community (SGLB).

then a camera (Canon 600D) was placed on the tripod at each sample point. At a horizontal angle of view, 1.5 m from the ground, panoramic images in four directions were captured at each sample point. With reference to the general definition and measuring method in the Guide to the Investigation and Research of Green Visual Ratio (15, 16), Adobe Photoshop CS6 was applied to correct the image and extract the contour of the green part, including plant leaves and water bodies while excluding branches and blocked parts. The calculation formula is: GVI = green part area/total photo area × 100%. The GVI value and the average GVI value of the research community were obtained.

2.4. Statistics and analysis

Excel and IBM SPSS Statistics 25.0 software were applied to collect and analyze the survey data of community green exposure index, spatial perception, and activity behavior, following the relevant associated analysis. Analysis methods include descriptive analysis to uncover the basic characteristics of the research object and the research community. Exploratory factor analysis of the perception measure item extracts the three perception factors with the highest correlation degree according to the factor load and determines the perception dimension of community green space. Mean comparison analysis and regression analysis verify the impact of the green exposure index on community green spatial perception and activity behavior, and to a certain extent indicate that spatial perception may participate in the influence path as an intermediate factor. According to the regression results and research hypotheses, the AMOS structural equation model was constructed to explain the action path of multi-dimensional spatial perception in the process of green exposure index inducing activity behavior and reveal the internal correlation path of green exposure index, multi-dimensional spatial perception, and activity behavior.

3. Results and analysis

3.1. Description of basic information

By conducting a related investigation, complete and valid data on 398 respondents in total in the nine residential communities were obtained (Table 2). In this table, the CH communities (HLW, JNFT, LZLC, and NZY), together with the UC community XFY, was built in this century. The SH communities (SHY, XLY, SGLB, and SGLA) were built from the 1970s and 1980s to the beginning of this century, covering an area that was generally smaller than the CH

TABLE 1 Community green spatial perception evaluation index system.

Factor no.	Perception factor	Measuring item no.	Perception measuring items	Measuring problem
Q	Perceived landscape quality	Q1	Naturalness	The naturalness of plant landscape; the diversity of vegetation species; the variety of topography.
		Q2	Aesthetics	The aesthetics of design elements; tranquil landscape experience.
A	Perceived accessibility	A1	Safety	Sense of security; sense of shelter.
		A2	Friendliness	Freedom to experience; spatial sense of belonging.
		A3	Connectivity	The difficulty level of entering and accessing to green space.
U	Perceived workability	U1	Cleanliness	Care and maintenance for green space; vegetation trimming and conservation.
		U2	Facility integrity	Proportion of space for activity facilities; the variety of activity facilities.
		U3	Functionality	The usability of dynamic and sedentary activities.

TABLE 2 The information list of the research community.

Community name	Housing attribute	Time of construction/year	Floor space/m^2	GVI	NDVI	Number of respondents
HLW	CH	2007	167,500	54.0%	0.521	52
JNFT	CH	2004	29,700	52.9%	0.407	47
LZLC	CH	2004	28,600	53.0%	0.337	54
NZY	CH	2000	10,400	26.0%	0.228	19
XFY	UC	2001	45,800	55.3%	0.419	53
SHY	SH	2000	5,700	19.5%	0.397	47
XLY	SH	2000	3,400	32.3%	0.382	53
SGLB	SH	1980	16,200	9.5%	0.194	48
SGLA	SH	1970	4,900	12.7%	0.205	25

communities and the UC community. It was observed from space information analysis that the GVI value of the research community was concentrated between 10 and 60%, while the NDVI value was concentrated between 0.20 and 0.60. Both the GVI and NDVI of the SH communities were lower than those of the CH communities and the UC community.

3.2. Analysis of community green spatial perception and activity behavior

Perception-measuring items with more than four scores are considered of significance or with positive value. According to the comparison analysis of spatial perceived importance attribution and activity behavior evaluation (Table 3), there was a certain relationship between the proportion of residents with perceived importance and the mean value of activity behavior evaluation. In other words, it was indicated that the higher the number of perception-measuring items with positive values (the proportion of residents was over 50%), the higher the mean value of activity behavior evaluation, especially the PF value. For example, the proportion of importance of eight perceived measuring items in the XLY community was over 50%, and the mean value of evaluation of PT and PA was higher than other communities, while in the XFU community, only two perceived measuring items had an importance of more than 50%, along with the lowest mean value of evaluation of PT and PA. The above results indicated that there may exist a correlation between space-perceived measuring items and activity behavior in the research community.

According to the community green exposure index and linear regression analysis (Table 4), GVI and NDVI negatively affected the three perception factors, among which perceived landscape quality was most affected. Specifically, GVI exerted a more prominent impact on the seven perception factors except the friendliness factor ($P < 0.05$). NDVI had no obvious impact on friendliness and security factors but exerted a significantly negative impact on the rest of the six perception measuring items ($P < 0.05$). The results

TABLE 3 Spatial perception importance attribution and activity behavior evaluation analysis.

Community name	Proportion of people evaluating spatial perception importance (%)								Mean value of the activity behavior evaluation	
			A1	A2	A3	U1	U2	U3	PT	PA
HLW	16.7	14.8	66.7	72.2	42.8	5.6	11.1	29.7	3.20	3.96
JNFT	17.0	29.8	51.1	65.9	35.2	8.5	0	57.4	3.32	3.98
LZLC	18.5	29.7	63.0	59.3	59.3	9.3	25.9	33.4	2.44	3.48
NZY	15.8	21.1	57.9	84.3	79.0	5.3	15.8	52.7	3.11	4.05
XFY	16.4	10.9	76.4	90.0	32.7	5.5	7.3	25.5	2.85	3.36
SHY	74.4	67.9	74.4	84.5	80.9	23.4	44.7	55.3	3.17	3.79
XLY	100	83.6	89.1	72.7	87.2	61.8	63.7	98.2	3.69	4.15
SGLB	65.3	69.3	77.6	67.3	98.0	26.5	65.3	64.3	1.59	4.51
SGLA	52.0	36.0	64.0	64.0	28.0	24.0	12.0	80.0	3.20	3.84

TABLE 4 Unitary regression analysis of community green exposure index and spatial perception.

Perception measuring item	GVI			NDVI		
	B	*F*-value	*P*	*B*	*F*-value	*P*
Perceived landscape quality	−0.500	134.108	0.000	−0.274	32.706	0.000
Naturalness	−0.504	136.904	0.000	−0.262	29.586	0.000
Aesthetics	−0.432	92.502	0.000	−0.252	27.330	0.000
Perceived accessibility	−0.280	34.401	0.000	−0.168	11.636	0.001
Safety	−0.120	5.877	0.016	−0.059	1.409	0.236
Friendliness	−0.080	2.619	0.106	−0.28	0.322	0.571
Connectivity	−0.369	63.620	0.000	−0.249	26.557	0.000
Perceived workability	−0.459	107.450	0.000	−0.274	32.708	0.000
Cleanliness	−0.319	45.510	0.000	−0.191	15.280	0.000
Facility integrity	−0.404	78.783	0.000	−0.207	17.982	0.000
Functionality	−0.433	93.025	0.000	−0.297	38.908	0.000

of community spatial perception and activity behavior regression analysis (Table 5) indicated that the three perception factors and their measuring items all positively affected the activity frequency, except that the workability and cleanliness factors all positively affected the activity time.

3.3. Analysis of the association path between green exposure index and activity behavior based on spatial perception

The statistical analysis of the above data suggested that the community green exposure index may be associated with activity behavior through spatial perception factors. To clarify the relationship among the three factors, the following hypotheses were proposed: (1) the green exposure index directly affected the spatial perception factors and caused activity behavior and (2) the perception factors were internally involved in the process of the green exposure index affecting activity behavior through spatial perception. Based on the above hypotheses, a structural equation model (Figure 3) was constructed, and then activity behavior (activity frequency and activity time) was included in the model as a latent variable to be examined. Though the goodness-of-fit of the hypothesis model was overall high, perception factors exerted an inconspicuous impact on the activity behavior (the results are not shown). The model was rebuilt after excluding the activity time, which led to a hybrid model based on activity frequency response. It was observed that the fitted values of major testing indicators were all within the recommended range (Table 6), which indicated that the hypothesis model could match the statistics with high goodness-of-fit. The above data supported the hypotheses proposed by the model.

In the hypothesis-testing results of the structural equation model (Table 7), the results of hypothesis paths H1, H3, H5, H6, and H9 passed the *t*-test ($P \leq 0.05$). It demonstrated the successful establishment of the hypothesis paths and indicated that there existed some influence rule between the green exposure index and the activity frequency of the residents under the intermediate effect of perception factors (perceived landscape quality, perceived workability, and perceived accessibility). The realistic hypothesis model was obtained after sorting out related statistics (Figure 4),

TABLE 5 Unitary regression analysis of community spatial perception and activity behavior.

Perception factor/measuring item	Activity time			Activity frequency		
	B	*F*-value	*P*	*B*	*F*-value	*P*
Perceived landscape quality	0.084	2.837	0.093	0.148	9.080	0.003
Naturalness	0.093	3.489	0.062	0.136	7.607	0.006
Aesthetics	0.064	1.637	0.202	0.142	8.332	0.004
Perceived accessibility	0.071	2.014	0.157	0.235	23.457	0.000
Safety	0.081	2.640	0.105	0.179	13.318	0.000
Friendliness	0.021	0.180	0.672	0.114	5.348	0.021
Connectivity	0.048	0.941	0.340	0.199	16.606	0.000
Perceived workability	0.114	5.265	0.022	0.238	24.226	0.000
Cleanliness	0.143	8.410	0.004	0.165	11.275	0.001
Facility integrity	0.086	3.007	0.084	0.202	17.139	0.000
Functionality	0.055	1.244	0.265	0.234	23.347	0.000

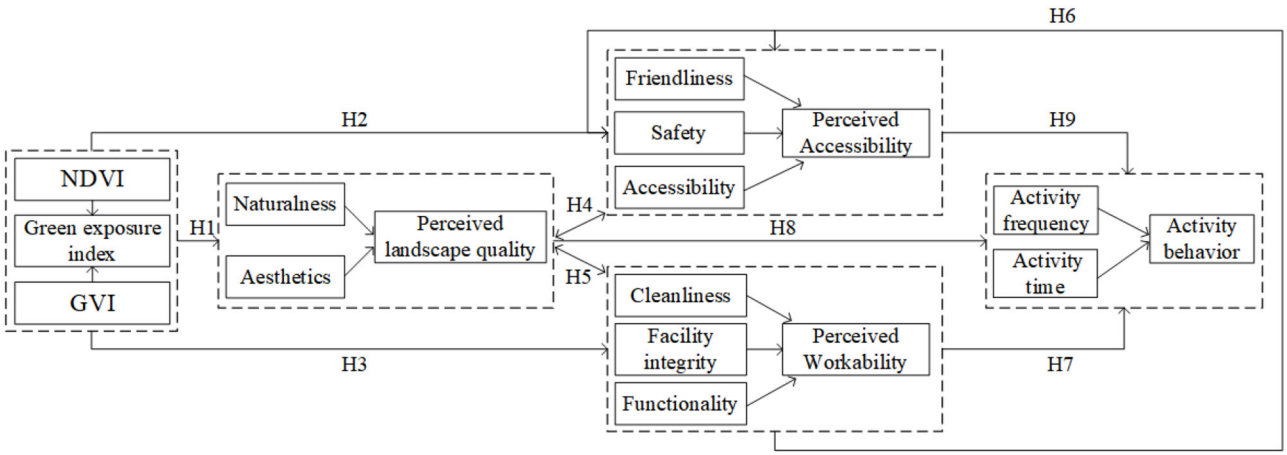

FIGURE 3
The concept model.

in which the green exposure index first negatively affected the perceived landscape quality and then positively affected the perceived workability and accessibility, respectively, finally exerting a positive impact on the activity frequency. This model demonstrated that the green exposure index could indirectly affect the frequency of outdoor physical activity among residents through the intermediate function of perception factors. Moreover, there was a close internal correlation and response path among the three dimensions representing perception factors (perceived landscape quality, perceived workability, and perceived accessibility).

4. Discussion

4.1. Identification and description of urban green spatial perception factors

Since the 1970s, environmental psychologists have proposed that natural landscape perception can significantly improve emotions and affect behavior. The natural environment information forms aesthetic preferences through sensory contact and stimulates emotional responses and neurophysiological activities. Therefore, perception is seen as an intermediate process between the natural environment and the behavioral response (17–19). As the representative subject of the natural environment in urban cities, urban green space exerts a profound impact on modern human space experience, daily behavior, and physical and mental health (20). Through relevant literature, it is found that the perceptual attributes of urban green space can be divided into two dimensions: one is perceived landscape quality attribute which focuses on the universality and significance of natural landscape aesthetics (21–23), covering a wide range of characteristic indicators including complexity, aesthetics, naturalness, culture and history, openness, serenity, comfort property, and species diversity (24–27), and the other is perceived use attribute that emphasizes on green space ecosystem services and management functions (28), generally targeting green space

TABLE 6 The value of fit indices of the structural equation model.

Fit indices	Recommended value	Fitted value
χ^2/df	<3.0	2.290
GFI	>0.9	0.964
AGFI	>0.8	0.932
RMSEA	<0.08	0.057
NFI	>0.9	0.953
IFI	>0.9	0.973
CFI	>0.9	0.973

units such as parkland or neighborhood community green space and including various characteristic indicators such as cleanliness, site and facility characteristics, safety, convenience, functionality, walking accessibility, and social nature (29, 30). Although some perception variables were sorted out through investigation and regression analysis, there were two major problems in previous studies. First, empirical studies generally discussed the binary relationship between physical attributes and behaviors of green space, ignoring the quantitative relationship between the intermediate roles of perception variables. Second, few analyses revealed the internal relationship between perception variables. It is generally believed that perception variables are in the same perception dimension, ignoring the multi-dimensions of human attention to landscape and the relationship between different dimensions. This research proposes the hypothesis that the green exposure index affects activity behavior through spatial perception, highlighting the significance of multi-dimensional spatial perception. The research method is a supplement to the binary relationship between green exposure and activity behavior, which has a certain exploratory nature.

4.2. Influence of green exposure index on spatial perception and activity behavior

In this study, GVI and NDVI constitute important green vegetation indices from two dimensions to facade space, and they are considered measuring indices that practically and effectively examine the relationship between three-dimensional perceived green quantity and population health. According to the survey of the Ministry of Land, Infrastructure, Transport and Tourism of Japan, a GVI of more than 25% can render a better view of greening and make people feel visually comfortable. Moreover, a large number of scholars have found that GVI between 30 and 50% can produce a nice landscape, relieve fatigue, or gather crowds of people, and there is an inverted *U*-shaped relationship between space satisfaction, pressure recovery, and GVI. That is to say, as the GVI value increases, the landscape satisfaction may be reversed and the pressure recovery may be hindered (31, 32). In addition, in neighborhood spaces with medium and high levels of NDVI, residents tend to spend more time taking recreational physical activities in summer, but increased NDVI values may also reversely reduce the level of walking or cycling (33). In this study, the green exposure index had a negative impact on all the spatial perception measuring items, and the higher the GVI and NDVI values were, the lower the community perception factor evaluation was, which indicated that people had a higher degree of preference or sensitivity to community green space with moderate GVI and NDVI values. When the greening degree was too high, vegetation became so dense that people's views may be blocked, which may adversely affect the three perception dimensions as well as activity behavior.

4.3. The internal association path of green spatial perception on activity behavior

Psychological evolution theory suggests that natural environment information is the first to interact through visual perception in contrast to other sensory perceptions. The overall structure, depth characteristics, and scene categories of the natural landscape will directly affect individual visual perceptual attributes and then activate adaptive behaviors or functions through aesthetic preference, cognitive advantages and disadvantages, and behavioral motivation, and finally forming an emotional response process in the natural landscape. Therefore, GVI as a green visual index, in contrast to the two-dimensional vegetation cover evaluation index NDVI, may exert a more prominent impact on the community's green spatial perception factors evaluation and activity behavior as it reflects the overall characteristics of green space and space sensory experience with the fastest speed (34). On the other hand, brain science experts and human geographers have found that emotions are stimulated by the external environment and that emotions drive behavior. As two major expressions of emotions in man–land relationships, love and fear dominate people's emotions, making them go after advantages and avoid disadvantages (35). The unity of opposites of love and fear constitutes the basis for people to understand the dialectical relationship between man and space, so the brain mechanism behind the adaptive behavior of "going after advantages and avoiding disadvantages" constitutes the basic process for organisms to adapt to the environment (36). In this study, the green exposure index affected activity behavior through the intermediate effect of the internal perception path of perceived landscape quality, perceived workability, and perceived accessibility, indicating that the three perception dimensions, under the emotional response framework, may be regarded as intermediate response factors in the process of aesthetic preference to cognitive advantages and disadvantages; that is, the community green space environment affected subjective cognition and behavioral motivation and finally motivated activity behavior through sensory interaction to stimulate the responsive process of the overall quality preference evaluation (at the natural environment level), landscape workability preference (at the environment-individual interaction level), and landscape accessibility preference (at the cognitive level of advantages and disadvantages of natural environment). Therefore, the impact of the green exposure index on activity behavior was first based on the intermediate function of spatial perception which only affected activity frequency without affecting activity time, further

TABLE 7 Hypothesis-testing results of the structural equation model.

Path no.	Hypothetical relationship	Normalized path coefficient	*t*-value	Hypothesis supported or not
H1	Green exposure index ↔ perceived landscape quality	−0.482***	−8.796	Yes
H3	Green exposure index ↔ perceived workability	−0.459***	−7.743	Yes
H5	Perceived landscape quality ↔ perceived workability	0.834***	9.283	Yes
H0	Green exposure index → activity frequency	0.041	−0.881	No
H2	Green exposure index → perceived accessibility	−0.111	−1.765	No
H4	Perceived landscape quality → perceived accessibility	−0.004	0.983	No
H6	Perceived workability → perceived accessibility	0.652***	3.544	Yes
H7	Perceived workability → activity frequency	0.273	1.705	No
H8	Perceived landscape quality → activity frequency	−0.232	−1.786	No
H9	Perceived accessibility → activity frequency	0.275**	2.380	Yes

Significance ***$P < 0.001$; **$P < 0.01$.

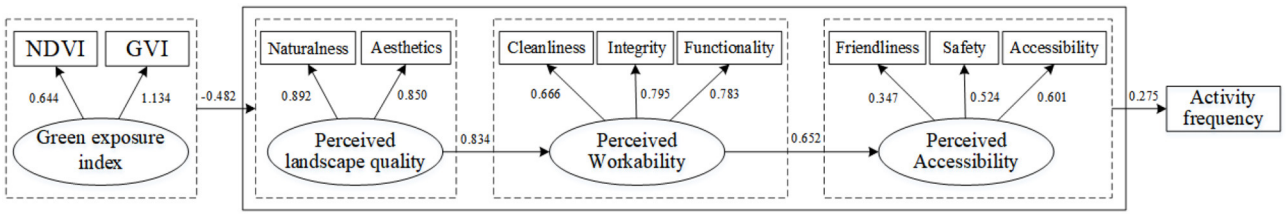

FIGURE 4
The realistic hypothesis model.

demonstrating that spatial perception, which formed the basis of the instantaneous emotional response process, may stimulate activity motivation by fast responding to the internal perception level so as to affect personal decision-making when conducting activities but is unable to affect the time-space continuity of activity behavior.

4.4. The spatial pattern of the community green spatial perception

In recent years, the research method of combining the spatial metrics of the green exposure index with micro evaluation of spatial perception has been regarded as a new method that forms a qualitative research framework based on quantitative analysis of urban green space quality. Through empirical analysis, it is found that a large number of influencing factors are mixed in issues concerning urban green space, physical activity behavior, and health (37), and the potential internal association as well as the spatial pattern of these issues need to be considered within places of specific scales (25). Therefore, the impact of community green space quality on spatial perception can be adjusted to some extent by identifying residence-based buffer areas. During the investigation process, it was commonly suggested by the research subjects and investigators that the greening quality and public facilities of the community with security housing represented by the Xinglongyuan community were obviously poorer than those of communities with commercial housing and units, but the proportion of importance of the eight perception measuring items and the mean value of spatial perception evaluation (the results were not shown) were significantly higher than those of the other communities. Concerning the reason for the above findings, on the one hand, in the Xinglongyuan community, as a community with security housing, the green exposure index remained at the medium level. On the other hand, most communities with security housing covered a floor area of <10,000 m^2, which meant that the buffer area covered an area of <100 m. Therefore, a smaller floor area may have a more direct impact on people's space experience and activity behavior in the community green space with activity boundaries.

4.5. Limitations

In this study, the activity behavior survey mainly focused on the activity time and frequency of middle-aged and older adults in the community, and other factors of activity behavior were not explained. During the investigation, it was found that some older adults' evaluation of activity behavior may be inaccurate. In addition, the survey respondents were generally middle-aged and older adults aged 50–70 years, and the research conclusions may have a group phenomenon. In future research, it is necessary to improve the research scheme based on different age groups.

5. Conclusion

Green exposure index, spatial perception, and activity behavior have an internal influence relationship, and the effect of the green exposure index on activity behavior is based on the intermediate role of spatial perception. Spatial perception, as the basis of an instantaneous emotional response process, may stimulate activity motivation through the rapid response of the internal perception level and influence individuals' decisions to implement activity behavior. It is worth noting that the influence of the green exposure index on spatial perception and activity behavior is limited by activity area and activity boundary.

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 authors.

Author contributions

LZ: conceptualization, methodology, software, data curation, writing—original draft preparation, and writing—review and editing. YZ: methodology and writing—review and editing. RD: methodology, writing—review and editing, supervision, and funding acquisition. ZW and JS: conceptualization and supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Green physical activity for leisure connects perceived residential greenspace and mental well-being

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Physical activity serves as a pivotal mediator in previous theoretical frameworks that link greenspace and human health. However, it remains unclear whether the domain of physical activity within and around greenspaces can alter the pathway. The present study recruited 668 participants online and examined a conceptual framework that explores the associations between residential greenspace and mental well-being, with a particular focus on the mediation effect of green physical activity (physical activity undertaken in and around greenspaces). Moreover, socio-demographic characteristics, including gender, age, household income, education status, marital status, and student status, were controlled for during the examination. The investigated green physical activities included leisure activities, transportation walking, and transportation cycling, and they were measured by a pre-established questionnaire. Meanwhile, mental well-being was measured by the WHO-5 well-being index, and residential greenspace was indicated by self-reported perceived greenspace and mean Normalized Difference Vegetation Index (NDVI) values within 500 meters (m) of residential radius. We found that both perceived greenspace ($B = 1.852$, $p < 0.001$) and NDVI $_{500\ m}$ ($B = 3.230$, $p = 0.038$) were positively associated with mental well-being. However, only perceived greenspace, not NDVI 500 m, exhibited positive associations with the three green physical activity items. Furthermore, only green physical activity for leisure ($B = 0.223$, $p < 0.001$), not for transportation ($p > 0.05$), mediated the relationship between perceived greenspace and mental well-being. Our findings reinforce previous studies on "greenspace-health" frameworks and underline the importance of leisure physical activity in promoting mental well-being.

KEYWORDS

urban greening, neighborhood, greenery, recreation, model

1. Introduction

Greenspace plays a pivotal role in the promotion of public health, such as reducing negative emotions, promoting postoperative rehabilitation, and preventing infectious diseases (1). Among different greenspaces, residential greenspace is particularly beneficial due to its long-lasting impacts on residents (2, 3). Existing literature has demonstrated that higher levels of residential greenspace are associated with improved mental health and well-being (4, 5). To date, numerous theories and frameworks have been developed to investigate the mechanisms that underlie these positive associations. For example, lower psychological stress and greater social contact are potential mediators between greenspace and health/well-being. Notably, physical activity is often mentioned as a key mediator (6–8). This mediatory role of physical activity is primarily based on the assumption that greenspace may reduce disturbances such as air

pollution, noise, and heat, consequently creating a comfortable environment for physical activity (6, 7, 9). Moreover, residential greenspace may also foster an emotional attachment to nature and attract people to interact with nature, thereby increasing their physical activity levels (2).

Physical activity in natural settings, such as greenspace, is sometimes defined as green physical activity (10, 11). This concept has attracted significant research attention due to its potential benefits derived from nature exposure and physical activity (12). Although many studies have explored the relationship between greenspaces and physical activity, few have confirmed whether the observed physical activities actually took place within the greenspaces. Consequently, their findings may not effectively support the existing assumption that greenspaces promote physical activity by providing comfortable environments (6). For example, some physical activities may occur indoors, such as in gyms or urban centers, particularly considering the growing reliance on urban facilities among urban residents (13, 14). Furthermore, while recent studies have identified positive associations between residential greenspace and green physical activity, there are also studies that report non-significant associations between the two (15, 16). This discrepancy could be attributed to the variations in modes/types of physical activity (17) and the measures of greenspace (18). These uncertainties leave the pathway from residential greenspace to green physical activity unclear.

Typically, physical activity can be categorized by various domains, including "leisure," "transportation," "occupation," and "household" physical activity (19, 20). Greenspaces are public open areas that often contain recreational facilities or are strategically situated alongside roads to mitigate environmental disturbances, making them particularly conducive to leisure and transportation-related physical activities. Thus, the present study aimed to investigate the association between residential greenspace and mental well-being through these specific green physical activities. To visualize our research objectives, we developed a conceptual model as follows (Figure 1). Our hypotheses were:

> *H1:* Different green physical activities are positively associated with mental well-being.

> *H2:* Residential greenspace is positively associated with green physical activities and mental well-being.

> *H3:* Different green physical activities mediate the relationship between residential greenspace and mental well-being.

2. Materials and methods

2.1. Study design and participants

We conducted an online cross-sectional survey from April 25–30, 2023. We aimed to recruit urban residents as our participants. Due to our limited research sources, we distributed recruiting messages to volunteer chat groups (e.g., survey volunteer and community volunteer groups) through QQ and WeChat platforms. We also used the snowball method to encourage the initially recruited participants to call for participation through their social circles. The study's topic was described as an investigation of residential urban greening and physical activity. Details of the research questions were not disclosed. We offered compensation of 5 renminbi (RMB) for participation. It is noteworthy that one RMB was roughly equivalent to 0.14 US dollars as of August 2023. Participants were required to use WeChat accounts that linked their personal legal IDs so as to ensure that they were real people. Their device, WeChat ID, and IP address were monitored to avoid repeated participation. Inclusion criteria were: (1) having a fixed residence in cities; (2) living in the fixed residence during the recent month; and (3) being at home while completing the questionnaire. Exclusion criteria were: (1) no informed consent was provided; (2) questionnaires with unfinished items; (3) individuals who failed verification tests (to confirm that the questionnaire was carefully completed by people instead of a machine or program or random filling); and (4) at places other than home (verified through questions in the survey). Considering the potential ethical issues in GPS-based studies (21), we collected momentary data (not continuous or historical data) through a third-party platform (GaoDe AutoNavi Holdings Ltd.) that is licensed and supervised by the Chinese government. The geo-information was uploaded manually by the participants (we were not able to access their smartphones). We explained our use of location information, including purpose, accuracy, and the form of the information, before the survey began. Written consent was obtained from all individuals before the investigation (those who did not submit consent material were not allowed to participate). Furthermore, our survey is conducted entirely

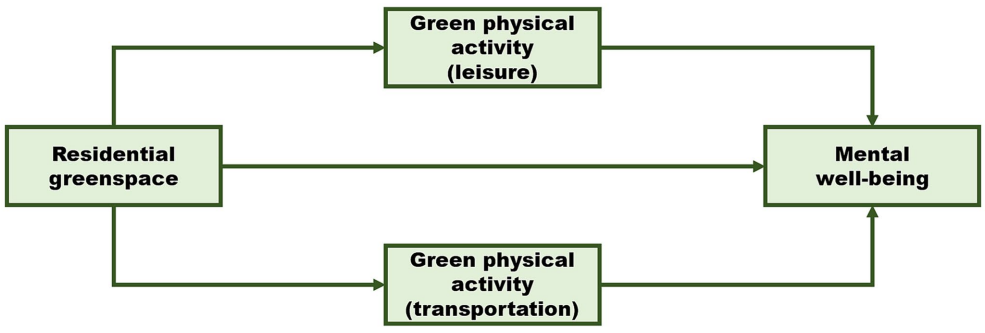

FIGURE 1
The conceptual framework.

anonymously to avoid the invasion of privacy. This study was approved and supervised by the Ethics Review Board of Southwest University.

2.2. Instruments and measurements

2.2.1. Greenspace assessment

We considered both measured and perceived greenspace for indicating the overall amount of greenspace in residential neighborhoods.

2.2.1.1. Measured greenspace

We used a locating service empowered by GaoDe AutoNavi Holdings Ltd. to capture the coordinates of our participants via the GPS functions in their smartphones. We used the Normalized Difference Vegetation Index (NDVI) to reflect measured greenspace, which is a useful measure of neighborhood greenness that has practical advantages and may aid in replication and comparability across studies (22, 23). We used Google Earth Engine (GEE) to obtain the maximum annual NDVI of China (for the year 2022) based on a MODIS product from NASA (code: MOD13Q1), which has a 250×250 meter (m) spatial resolution. Thereafter, to avoid the NDVI observation of water masking the existence of vegetation, we followed the recommendations of others by removing negative values before analysis (5, 6). We referred to previous studies and established buffers with a 500 m radius around participants' residences (4, 24). The mean NDVI value extracted from the buffers was regarded as the overall greenness in residential neighborhoods.

2.2.1.2. Perceived greenspace

We asked the participants to estimate the overall amount of greenspace in their residential neighborhood (25–28). The statement was "Please rate the greenspace level (amount) in your neighborhood. For example, are there many trees and grassland?" The response was captured by a 10-point NRS scale, where 1 = none and 10 = extremely sufficient. Previous studies have found that data from such a measure on perceived greenspace is associated with mental health in a similar population (25, 26), which suggests the measure has relevance to mental health.

2.2.2. Green physical activity

For leisure green physical activity, we modified the items by Troped et al. (29) to match the green physical activity scenarios. We used "How many days per week in the past month have you engaged in leisure physical activity or exercise (such as walking and aerobics) in a greenspace (e.g., with trees and grassland)?" to measure the frequency of leisure green physical activity. The results were measured using an 8-point Likert scale (where 1 point indicates "never" and 8 points indicates "almost every day"). Meanwhile, we used "How long did each bout of the above-mentioned activities last on average?" to measure the duration of each bout of leisure green physical activity. The results were measured using a 10-point Likert scale (where 1 point indicates "0–10 min" and 10 points indicates "90 min or more"). The product of the scores for both options was considered the total score of leisure green physical activity. For transportation green physical activity, we used two questions by Troped et al. (29) to measure walking and cycling-related green physical activity. According to Troped et al. (29), the questions are from the MOSPA survey on walking and bicycling. The question about walking was "On average, how long did you walk in a greenspace (e.g., through a park or community trail) for transportation purposes per day in the past month?" The question about cycling was "On average, how long did you cycle in a greenspace (e.g., through a park or community trail) for transportation purposes per day in the past month?" The results of both questions were measured using a 10-point Likert scale (1 point indicates "0–10 min" and 10 points indicates "90 min or more").

2.2.3. Mental well-being

The WHO-5 well-being index was used to measure mental well-being, as suggested by previous studies (5, 30). This scale consists of seven items, such as "I have felt calm and relaxed" and "I woke up feeling fresh and rested." Answers were obtained on a 5-point Likert-type scale (0 = never, 4 = every time). To better associate mental well-being with our other variables (e.g., green physical activity), we used "over the last month" as the time frame for these questions. We used a Chinese version of WHO-5, and it showed good internal consistency in the current study (Cronbach $\alpha > 0.9$). The summary score of WHO-5 was used to represent mental well-being in the subsequent analyses.

2.2.4. Control variables

We included sociodemographic factors as control variables to adjust for the associations in our framework. Gender, age, and marital status may influence individuals' likelihood of visiting greenspaces and their mental well-being (31, 32). Household income and education status are critical indicators of an individual's socioeconomic status (SES) (33), which may affect both the likelihood of residing in areas with abundant greenery and mental health outcomes (34). Similarly, student status, which is associated with campus life, can significantly impact individuals' residential environment (e.g., campus greening) as well as their behavior and health, and was therefore included as a control variable as well. These sociodemographic factors were measured as follows:

Gender (0 = male and 1 = female), age (coded as: 1, ≤15; 2, 15–25; 3, 26–35; 4, 36–45; 5, 46–55; 6, 56–65; 7, 66–75; 8, ≥75 years), education status (coded as: 1, lower than undergraduate; 2, undergraduate; 3, higher than undergraduate), household income (coded as: 1, 0–5,000 RMB; 2, 5,001–10,000 RMB; 3, 10,001–15,000 RMB; 4, 15,001–20,000 RMB; 5, 20,001–25,000 RMB; 6,>25,000 RMB monthly), and student status (0 = yes and 1 = no), marital status (0 = yes and 1 = no).

2.3. Analysis

2.3.1. Correlation

Given the nonnormal data, Spearman's rank-order correlation was used to probe for general correlations between two continuous variables of interest.

2.3.2. Structural equations modeling

Based on our employed measures, we developed a framework with three green physical activity mediators. Considering the potential interrelationships among the three types of green physical activities, we established covariance links to account for co-variation. The specific conceptual model was demonstrated in Supplementary Figure S1.

Structural equation modeling (SEM) was employed to investigate the hypothesized associations and mediation effect. According to MacCallum et al. (35), the sample size for SEM should be ten times the number of model parameters or more. Based on the parameters ($n = 42$) required to estimate in the framework, our sample size of 668 was adequate.

Variance Inflation Factor (VIF) values smaller than 5.0 were considered evidence of the absence of multicollinearity. Based on this rule, no multicollinearity was observed among the independent variables (VIF < 3.0) (36).

The analysis was conducted using the Maximum Likelihood (ML) estimator. To cope with the nonnormality, we used the bias-corrected bootstrap method (37) with 10,000 replications to generate corresponding standard errors and confidence intervals for all paths (38–40). Meanwhile, given that the χ^2 test is strongly affected by nonnormality (41–43), we turned to the Bollene-Stine statistic to check the overall model fit (44–46), where $p_{\text{Bollene-Stine}} > 0.05$ is a sign of acceptable model fit. Additionally, common model fitting indices were also reported. Their titles and criteria were: Standardized Root Mean Square Residual (SRMR) < 0.08; Tucker-Lewis Index (TLI) > 0.95; Comparative Fit Index (CFI) > 0.95; Root Mean Square Error of Approximation (RMSEA) < 0.05 (47).

An indirect effect (i.e., a product of coefficients for the constituent links) that significantly exceeded zero was evidence of mediation (48, 49). The total effects in the model were not interpreted as causality, but as the total associations realized through direct and indirect pathways.

All the statistical analyses were conducted in SPSS 26.0 and AMOS 26.0 software.

3. Results

3.1. Participants characteristics

Our participants were mainly male, aged between 26 and 35 years, and having a monthly household income of 50,001 to 10,000 RMB (Supplementary Table S1). Around 60% of participants were unmarried, 47.9% were students, and 63.8% declared to have experienced undergraduate education.

3.2. Correlations between variables of interest

We found that NDVI 500 m was negatively correlated with green cycling for transportation ($\rho = -0.090$, $p = 0.020$). Perceived greenspace was positively correlated with green physical activity for leisure ($\rho = 0.282$, $p < 0.001$), green walking for transportation ($\rho = 0.114$, $p = 0.003$), and mental well-being ($\rho = 0.534$, $p < 0.001$) (Supplementary Figure S2). Mental well-being was positively correlated with green physical activity for leisure ($\rho = 0.338$, $p < 0.001$) and green walking for transportation ($\rho = 0.133$, $p = 0.001$).

3.3. Pathway and mediation analysis

3.3.1. Model modification

Since only perceived greenspace was found to positively associate with both green activities and mental well-being, we loaded the conceptual model with perceived greenspace for assessing the hypothesized mediation effect. The initial model showed poor model fits ($p_{\text{Bollene-Stine}} = 0.007$; SRMR = 0.016; CFI = 0.994; TLI = 0.886; RMSEA = 0.068 [90%CI: 0.031 to 0.109]). Therefore, we followed the modification indicator and built a covariance link between perceived greenspace and age. This modification is supported by previous studies suggesting that age is associated with changes in greenspace use and perception (32, 50). After the adjustment, the model showed acceptable model fits ($p_{\text{Bollene-Stine}} = 0.214$; SRMR = 0.009; CFI = 0.999; TLI = 0.981; RMSEA = 0.027 [90%CI: 0.000 to 0.086]) and was therefore selected as the final model. After that, we loaded the final model with NDVI 500 m and also obtained acceptable model fits ($p_{\text{Bollene-Stine}} = 0.250$; SRMR = 0.008; CFI = 0.999; TLI = 0.986; RMSEA = 0.022 [90%CI: 0.000 to 0.083]).

3.3.2. The associations between green physical activities and mental well-being

Only green leisure physical activity was found to positively associate with mental well-being when the three green physical activity items were simultaneously loaded as predictors in the two models (loaded with NDVI 500 m or perceived greenspace) (Figure 2).

3.3.3. The associations of greenspace indicators to green physical activities and mental well-being

According to the model loaded with NDVI 500 m, NDVI 500 m was negatively associated with green cycling for transportation ($p = 0.014$) but was positively associated with mental well-being ($p = 0.038$). In the other model loaded with perceived greenspace, perceived greenspace was positively associated with the three green physical activity items and also mental well-being (Table 1).

3.3.4. The mediatory role of green physical activities between greenspace and mental well-being

As shown in Table 2, green leisure physical activity was the only mediator to link perceived greenspace and mental well-being ($p < 0.05$). This pathway contributed to 12.04% of the total effect of perceived greenspace on mental well-being.

4. Discussion

The primary objective of this study was to investigate the mediating effects of green physical activities on the relationship between residential greenspace and mental well-being. Our findings revealed positive associations of both measured and perceived greenspace with mental well-being. Moreover, we identified leisure green physical activity as a significant mediator in the pathway from perceived greenspace to mental well-being. These results not only support previous studies on the association between greenspace and health (5, 6) but also emphasize the special role of leisure physical activity in this context.

4.1. Green physical activities and mental well-being

Green physical activities, also referred to as green exercise in many studies, have been anticipated to combine the health benefits of physical activity and nature exposure. However, previous research has often overlooked the distinctions among green physical activities within

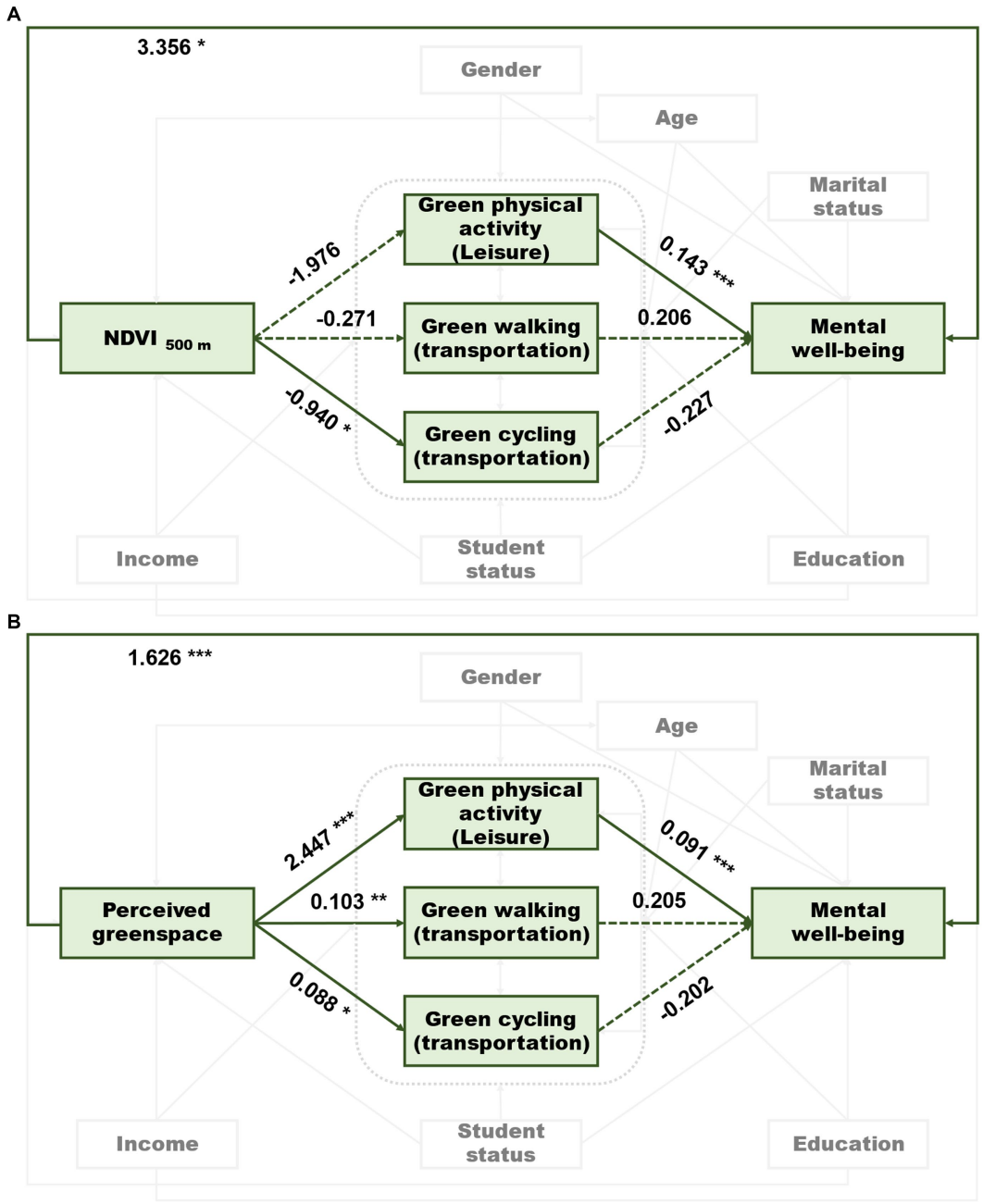

FIGURE 2
The final models showing the pathways from NDVI 500 m **(A)** or perceived greenspace **(B)** to mental well-being. Solid lines indicate significant pathways and dotted lines indicate non-significant pathways. Numbers are unstandardized regression coefficients.

various domains. In this study, we found that while green physical activity for leisure and transportation (specifically walking) exhibited positive correlations with mental well-being, only green physical activity for leisure, but not transportation, demonstrated a significant positive association with mental well-being in our model. This finding partially supports our first hypothesis (H1). Nevertheless, this result is inconsistent with some studies where mental well-being is positively associated with active transportation such as walking and cycling (51–53).

A possible explanation for this discrepancy lies in the fact that previous studies often focused on a single domain of physical activity without adequately controlling for other physical activities. For instance, individuals who have cultivated an active lifestyle through leisure physical activities may also prefer engaging in physical activity during transportation. In other words, leisure physical activity could confound the association between transportation physical activity and mental well-being. Therefore, it may be essential to consider the physical activities of different domains to reveal the true associations.

The observed disparity between green physical activity for leisure and transportation is understudied yet. However, it may be explained by the different tasks involved in each activity. Specifically, previous studies have suggested that the mental health benefits of green physical activity may be related to the restorative experiences during nature exposure (54–56), and the restorative experiences can be affected by the task within the activity, with those tasks requiring more directed

TABLE 1 Total effects of greenspace indicators on green physical activities and mental wellbeing.

Greenspace indicator	Green physical activities	B (95% CI)	*p*
$NDVI_{500\,m}$	Green PA (leisure)	−1.976 (−8.835, 4.519)	0.534
	Green walking (transportation)	−0.271 (−0.949, 0.403)	0.426
	Green cycling (transportation)	−0.940 (−1.680, −0.206)	0.014
	Mental well-being	3.230 (0.176, 6.189)	0.038
Perceived greenspace	Green PA (leisure)	2.447 (0.033, 0.173)	<0.001
	Green walking (transportation)	0.103 (1.787, 3.133)	0.006
	Green cycling (transportation)	0.088 (0.009, 0.166)	0.030
	Mental well-being	1.852 (1.590, 2.109)	<0.001

B, regression coefficient; CI, confident interval; PA, physical activity.

TABLE 2 Indirect pathways from greenspace to mental well-being.

Pathway	B (95% CI)	*p*
Perceived greenspace → Green PA (leisure) → Mental well-being	0.223 (0.136, 0.324)	<0.001
Perceived greenspace → Green walking (transportation) → Mental well-being	0.021 (−0.013, 0.078)	0.199
Perceived greenspace → Green cycling (transportation) → Mental well-being	−0.018 (−0.074, 0.007)	0.165
$NDVI_{500\,m}$ → Green PA (leisure) → Mental well-being	−0.283 (−1.304, 0.634)	0.521
$NDVI_{500\,m}$ → Green walking (transportation) → Mental well-being	−0.056 (−0.454, 0.066)	0.279
$NDVI_{500\,m}$ → Green cycling (transportation) → Mental well-being	0.213 (−0.055, 0.746)	0.117

B, regression coefficient; CI, confident interval; PA, physical activity.

attention leading to impaired benefits (57). Transportation green physical activity often entails a stressful or attention-consuming task (e.g., reaching the workplace or school on time), which may lead to lower mental health benefits. By comparison, leisure greenspace activity is usually carried out for recreation, which may demand less attention or other mental resources, thereby offering greater benefits.

4.2. Residential greenspace, green physical activities, and mental well-being

We observed a positive association between perceived greenspace and the three green physical activity items. In contrast, the association between measured greenspace (NDVI 500 m) and green cycling for transportation was negative. These findings only partially support our second hypothesis. While seemingly contradictory, these outcomes are not entirely unexpected. This is because NDVI only reflects the general "amount" of greenspace rather than its quality or accessibility (5). In China, urban greenspace development lags behind that of Western developed countries, resulting in many greenspaces being undeveloped areas rather than well-maintained urban green facilities. This characteristic makes them less likely to be used for leisure and transportation physical activity.

Notably, In our correlation analysis, perceived greenspace was not significantly correlated to measured greenspace, which is inconsistent with some studies (58) but somewhat supports the aforementioned assumption. These greenspaces may lack designated areas or pathways for activities, or they may be obstructed from view by walls or other obstacles. Consequently, participants are unlikely to perceive and use those greenspaces. Even worse, those untapped and unavailable greenspaces may even hinder green physical activities by occupying the land that could otherwise be used for available greenspace construction. As mentioned in a previous study (59), such inaccessible, non-walkable, or even invisible greenspaces may not even exist in the mental maps of residents. In contrast, perceived greenspace may be closely related to usable greenspaces, thus effectively predicting green physical activities. These findings partly support the notion that subjective variables (e.g., perceived greenspace) are stronger predictors of greenspace visitation (18, 60).

Regarding mental well-being, both measured and perceived greenspace exhibited positive associations with mental well-being. This finding supports our second hypothesis and aligns with relevant studies (5, 25). The positive association between perceived greenspace and mental well-being can be explained from many perspectives. On one hand, the mediation effects of green physical activity (as we identified) partially explained the association. On the other hand, extra pathways that are beyond our research scope may also contribute to this association. For example, regardless of accessibility and utilization, residential greenspaces may buffer environmental disturbances such as noise, air pollution, and urban heat (6, 7), and they may also improve emotional outcomes through visual contact through windows (30, 61, 62). These unmeasured pathways may collectively connect residential greenspace and mental well-being.

4.3. The mediatory role of green physical activity

In this study, we discovered that only leisure green physical activity mediated the association between residential greenspace and mental well-being. This finding partially supports our third hypothesis and offers a potential mechanism to comprehend the benefits of residential greenspace. As introduced earlier, while some studies have demonstrated the mediating role of physical activity between greenspace and mental health, few have investigated the specific locations where the physical activity took place (6). This issue/

limitation may explain why some studies have reported weak mediation effects of physical activity (63). In response to this gap, our findings provide evidence to support the existing framework outlining how greenspace contributes to human health (6).

Furthermore, our findings highlight that green physical activity for leisure, rather than for transportation, is pivotal for this association. This finding aligns with previous studies. For example, a study indicated that cycling for commuting purposes did not mediate the relationship between greenspace and self-reported health in the Netherlands (64). Another study showed that increased levels of walking for recreational purposes explained the relationship between perceived greenspace and physical health (65). The two studies collectively imply the influence of the domain of physical activity on health benefits, although they did not investigate the places where physical activity occurred either.

Generally, our finding is unsurprising because leisure activity is known to promote mental well-being (66, 67), and this benefit may come from the fact that leisure activity provides an escape from routines and daily lives, and offers positive experiences, such as fascination with nature, reflection, and mental relaxation (68).

4.4. Limitations

In China, the age group below 15 years constitutes 1.75% of the total population, while those aged 65 years and older make up 14.2%. However, our participants were primarily aged between 15 and 35 years, which deviates from China's general age structure. Considering that older Chinese residents tend to use greenspaces more often (69, 70), it is possible that we have underestimated greenspace utilization and its impact on mental well-being.

It is worth noting that our participant recruitment was limited to smartphone users in order to utilize the GPS function of smartphones. However, this approach introduces the potential for informant bias, as these participants may exhibit a stronger affinity towards electronic devices and modern technologies. Consequently, they might engage in fewer outdoor activities compared to individuals who infrequently or do not use smartphones.

The question items we used, including those for assessing perceived greenspace and green physical activity, are not from verified instruments. In fact, there is a lack of well-studied instruments for the two variables yet. As a result, our study might have been affected by high levels of measurement errors and common method bias. This flaw warrants future research to develop suitable measures and re-examine our findings.

Although the mediation analysis implies causal relationships between variables, it's crucial to acknowledge that we adopted a cross-sectional design to capture data. Therefore, causality cannot be confirmed. Subsequent studies may consider employing longitudinal designs or instrumental variables to further examine causality.

5. Conclusion

This study aimed to investigate the relationship between residential greenspace and mental well-being. Additionally, it also explored the mediating pathways involving green physical activities for leisure or transportation. Our results revealed that both perceived and measured greenspace were positively associated with mental well-being. Furthermore, green physical activity for leisure emerged as a significant predictor of mental well-being and acted as a mediator in the association between residential greenspace and mental well-being. These findings provide location-specific evidence to support the existing framework or theory of "greenspace-physical activity-health" and emphasize the importance of leisure physical activity.

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 humans were approved by the Ethics Review Board of Southwest University. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

HL: Data curation, Formal analysis, Investigation, Writing – original draft, Writing – review & editing. YL: Funding acquisition, Supervision, Writing – review & editing. ZW: Resources, Writing – review & editing. GZ: Methodology, Project administration, Supervision, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

Supplementary material

The Supplementary material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fpubh.2023.1254185/full#supplementary-material

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The impact of urban green space on the health of middle-aged and older adults

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Introduction: Urban green space is one of the most closely related ecosystem services to residents' lives, and it can be regarded as a preventive public health measure. Residents living in parks and other green environments can help improve their physical and mental health, reduce stress and even prevent crime and violence. Therefore, based on the actual situation in China, this paper analyzes the relationship between urban green space and the health of middle-aged and older adults and its mechanisms.

Methods: This study used multiple linear regression, based the data from the China Health and Retirement Longitudinal Study (CHARLS) in 2013, 2015, and 2018, to explore the relationship between urban green space and the health of middle-aged and older adults. At the same time, group regression was conducted to identify the heterogeneity of health effects of urban green space.

Results: The research shows that the increase of urban green space areas can significantly improve the health status of middle-aged and older adults. After a series of robustness tests, the results are still valid. In addition, the health effects of urban green space are different because of gender, age, education level, marital status residence, geographical location of the respondents and park quantity distribution. Further research found that reducing hot weather and optimizing air quality are the potential mechanisms of urban green space affecting the health of middle-aged and older adults, providing new evidence for the causal mechanism between urban green space and the health of middle-aged and older adults.

Discussion: This study expanded the research scope of the impact of urban green space on the health of middle-aged and older adults, covering a representative sample in China. The results show that urban green space has an important impact on the health of middle-aged and older adults. Policy suggestions are made to help cities optimize the landscape and residents to enjoy ecology.

KEYWORDS

urban green space, physical health, mental health, mechanism analysis, middle-aged and older adults

1. Introduction

Many countries around the world are facing the severe challenge of an aging population (1–3). According to United Nations data, by 2030, one-sixth of the people in the world will be over 60 years old. From 2020 to 2030, the population over 60 years old will increase from 1 billion to 1.4 billion. By 2050, the world's population over 60 years old will double to 2.1 billion. Between 2020 and 2050, the number of people over the age of 80 is expected to triple to 426 million. Similarly, the degree of population aging in China will continue to deepen rapidly, and the dilemma of "getting old before getting rich" is still challenging to break through (4). According to the "2021 National Bulletin on the Development of Ageing" issued by the China Municipal Health and Wellness Commission and the National Office for Ageing, by the end of 2021, there had been 267.36 million older adults aged 60 and above in China, accounting for 18.9% of the total population. There are 200.56 million older adults aged 65 and above in China, accounting for 14.2% of the total population. In order to actively respond to the concept of aging, China issued the Outline of Healthy China 2030, and the report of the 20th National Congress of the Communist Party of China further proposed to implement the strategy of actively responding to population aging and promoting the construction of healthy China. Protecting the physical and mental health of middle-aged and older adults and improving the quality of life of middle-aged and older adults is the meaning of the healthy China, and it is also an important measure to practice the people-oriented concept. However, due to aging, the physical and mental condition of middle-aged and older adults has changed obviously, and the possibility of suffering from diseases (such as chronic diseases and dementia) has increased (5). In addition to physical disorders, the frequency of mental illness among the older adults is also increasing (6, 7), depression, anxiety and other psychological problems are a significant burden for older adults around the world (8, 9). Mental illness has also been identified as the leading cause of non-fatal health loss in the world, and health problems caused by negative psychology, including self-harm, dementia and suicide, are also widespread, bringing heavy burdens to families and society. Promoting the physical and mental health of the enormous middle-aged and older groups is a position that cannot be ignored (10, 11).

In the process of aging, the optimization of social environment conditions is the key to improve the physical and mental health of older adults and promote the development of active aging. Urban green space not only beautifies the urban environment but also is the principal public place where urban residents live, which has a subtle influence on the lifestyle of residents (12, 13). In 1998, in the Basic Terminology Standard of Urban Planning, urban green space was defined as "green land specially used to improve the ecology, protect the environment, provide recreation places for residents and beautify the landscape." In 2002, the Classification Standard of Urban Green Space expanded the definition of urban green space and defined green space as "a kind of urban land with vegetation as the main existing form, which is used to improve urban ecology, protect the environment, and provide recreation places for residents and beautify the city." The utilization of urban green space not only includes the planning of space and function but also needs to pay attention to its role in the urban ecological environment, providing leisure and entertainment places and beautifying the city so as to create a comfortable living environment for the public. As an important part of the city, urban park green space has an important impact on the health of middle-aged and older adults. Regular physical activities in green spaces can indirectly or directly benefit the physical and mental health and happiness of residents (14, 15), and the benefits to the older adults are more obvious (16). This is because green spaces help residents get more exercise and relax. This significantly reduces not only cardiovascular disease, but also the health risks of respiratory disease, high blood pressure, paralysis, diabetes and other chronic diseases. A large number of studies have shown that urban green space has a health promotion function and can provide people with a series of ecosystem services and universal health benefits (17).

2. Literature review and theoretical mechanism

2.1. Literature review

The existing literature mainly focuses on the following aspects in discussing urban green space and the health of the older adults. Firstly, from the perspective of the improvement effect of urban green space on the residents' environment. Many studies believe that urban green space provides residents with good conditions for outdoor sports, and green space in different regions has diverse functions and provides health benefits for residents from different angles: urban green space is an outdoor space covered by green vegetation in urban areas, such as forests, parks, grasslands, green belts, river wetlands, etc. Green vegetation has a good air purification function, which can directly play the role of intercepting pollution particles through retention and attachment, and can also be realized by changing climate factors such as wind fields (18). Therefore, urban parks and green spaces can improve the ecological environment, reduce the level of urban pollution control, improve residents' quality of life, and thus improve their subjective well-being (19). Square green space can provide fitness venues, improve urban residents' sports and outdoor activities, improve residents' willingness and ability to exercise, strengthen their physique, and improve their physical function (20, 21). And outdoor social communication can improve individual emotional enthusiasm, enhance social cohesion, and campus residential green space can beautify the living environment.

Secondly, urban green space can also play a positive psychological healing effect. More and more evidence shows that outdoor activities are positively related to adults' mental health, and more contacting with green space can reduce people's anxiety and depression (22). More research results show that urban green vegetation can reduce urban noise pollution (23), so it is speculated that urban traffic noise is the chief culprit affecting people's mental health. Traffic noise will have adverse effects on children's neurological development through stress, worry and sleep quality (24).

Finally, from the existing research methods on the two, some scholars have quantified and drawn the urban green space by constructing a spatial model and analyzing the critical factors that affect people's health based on the GIS model and spatial data (25). Researchers use the CLM model developed in 2016 to predict neuropsychological data accurately, and then fully measure the design quality of urban green space (26).

The existing research has explored the relationship between urban green space and human health, providing us with rich perspectives

and profound insights, but there may be three areas for improvement. First, the existing research is more based on a specific city or region, based on manual survey data, to explore the impact of specific parks on the health of surrounding residents, which may not be universal. Secondly, the way of describing human health in existing articles is based on the incidence of a specific disease, or the individual emotional score is obtained by answering questions. Few kinds of literature comprehensively examine many aspects of human health and comprehensively describe the health level by combining the psychological and physical dimensions of the human body. Thirdly, most of the literature has empirically tested the relationship between urban green space and the health of the older adults but failed to explore the causal mechanism behind the relationship further.

Compared with previous studies, this study may have the following three contributions. First, the existing research focuses more on the influence of air pollution, extreme weather, urban development and community activities on the health of the older adults, and less literature puts urban green space and the health of the older adults into a unified analysis framework, which provides a new academic perspective for studying the health of the older adults. Secondly, the physical health status of individual samples is obtained by combining the incidence of acute and chronic diseases. Besides, the individual mental health status is obtained using the Depression Scale (CESD), and the individual depression emotion value is calculated, which can reflect the individual's physical and mental health level more comprehensively from the two latitudes of psychology and body. Thirdly, the study attempts to explain the internal mechanism behind the positive impact of urban green space on the health of the older adults from the perspective of improving urban high-temperature weather and urban air pollution and provide a richer perspective for related research.

Based on the above problems, this study uses the data from the China Health and Retirement Longitudinal Study (CHARLS) to analyze the impact of urban green space on the health of middle-aged and older adults. First of all, according to the acute and chronic diseases, eight adverse emotional problems, and two positive emotional problems in the questionnaire, the health status of residents is quantified in detail, and the health of middle-aged and older adults is divided into two dimensions: physical health and mental health. Secondly, the influence of urban green space on the physical and psychological health of middle-aged and older adults is empirically tested by multiple linear regression, and a series of robustness tests are also carried out to support the empirical results. And further, we identify the internal relationship between urban green space and middle-aged and older adults' physical and mental health. Finally, the heterogeneity is discussed from gender, age, and place of residence.

The possible marginal contributions of this study are as follows: First, different from the previous general and single indicators, this paper turns to a more specific and multi-dimensional measurement, measuring the health level of middle-aged and older adults from two dimensions of physical health and mental health, and more accurately analyzing the health effects of urban green space on middle-aged and older adults. Secondly, analyze and test the mechanism channels of urban green space affecting the physical health and mental health of older adults, supplement the existing research literature at the level of mechanism analysis, and explain the internal relationship between urban green space and the health of middle-aged and older adults from the perspectives of economics, environmentalism, and sociology. Thirdly, because of individual differentiation, a series of heterogeneity analyses, such as gender and place of residence are carried out. A more detailed classification discussion is carried out at the individual level so as to make suggestions on the integration and optimization of urban green space layout in the future and the guarantee mechanism of the health level of different older groups.

2.2. Theoretical mechanism

With the increasing urbanization of the world and the reduction of the relationship between man and nature, the impact of urban green space on human health has attracted more and more attention from academic circles. During the COVID-19 pandemic, that is, during the implementation of the social distance policy, restrictions on mobility, concerns about safety, and restrictions on access, it tended to use urban green space (UGS) to provide alternative space for social interaction and health (27). Through an online survey conducted from March to April, 2021, it was found that respondents will continue to use UGS during the pandemic and think it is more beneficial to health (28–31). Most studies have found that there is an overall positive correlation between green space and health (32, 33). Further, some scholars have found that normalized vegetation index (NDVI), vegetation coverage, park coverage and street lawn are positively correlated with mental health of the older adults (34–36). Recent research shows that being close to nature (such as parks, green spaces, etc.) can reduce the stressors related to loneliness and reduce the stress level (37–39). At the same time, some studies have proved that urban greening has a protective effect on cardiovascular risk factors, diseases and mortality (40, 41). Urban green space is a crucial resource to effectively improve urban environment and human health. More and more evidence shows their positive effects on health and wellbeing (42–44). Therefore, Hypothesis 1 is put forward.

> *Hypothesis 1:* Increasing urban green areas can better improve the health status of middle-aged and older adults.

High ambient temperature is related to many health effects, including premature death. The combination of global warming caused by climate change and the expansion of the global built environment means that urban heat island (UHI) is expected to intensify, accompanied by adverse effects on population health (45, 46). A large number of studies show that urban green space can effectively alleviate the heat island effect. By increasing the coverage area of green space, the urban thermal stress and global warming potential gas can be reduced to protect the environment to reduce the negative impact on people's health (47–50). Massaro et al. (51) based on the spatial regression model of remote sensing data, evaluated the extreme exposure of people to high temperature (LST) in the urban environment of 200 cities according to surface characteristics such as vegetation coverage and distance from water bodies. The research results showed that urban vegetation played a considerable role in reducing the exposure of the urban population to extremely high temperatures (LST). Therefore, Hypothesis 2 is put forward.

> *Hypothesis 2:* Urban green space can improve the health status of middle-aged and older adults by reducing the temperature value of sweltering weather.

By using the data from the large-scale survey of "the world's first-class harmonious and livable capital" in Beijing in 2018 to investigate the influence of subjective and objective characteristics of UGS on residents' self-rated health (SRH) and applying binary Logistic regression model. It is found that social interaction and air quality perception are the two main mediating variables that UGS affects residents' self-rated health (52). At the same time, some scholars further pointed out that the content of $PM_{2.5}$ in the air can be reduced by increasing the investment in urban green space. Particulate matter ($PM_{2.5}$ and PM_{10}) is an essential source of urban air pollution and poses a severe threat to the health of urban residents (53). Urban vegetation has a specific ecological function of reducing atmospheric particles and is vital in improving the urban atmospheric environment. Based on hourly measured data of particulate matter concentration and high-resolution remote sensing images, some scholars estimated the total reduction and removal rate of $PM_{2.5}$ and PM_{10} in the atmosphere by urban green space within the Fifth Ring Road in Beijing. It has been found that urban green space has a significant reduction effect on $PM_{2.5}$ and PM_{10} (54, 55). Some scholars take different types of green space as the research object and test the air ion concentration, $PM_{2.5}$ concentration, temperature, humidity, wind speed, and other indicators, and analyze the temporal and spatial characteristics of air harmful ion concentration and $PM_{2.5}$ concentration in different types of green space. The research shows that the concentration of atmospheric particles presents other trends throughout the day, and small particles ($PM_{2.5}$) offer a "low morning and evening, high noon" trend, while large particles (PM_{10} and TSP) follow the trend (56). Therefore, Hypothesis 3 is put forward.

> *Hypothesis 3*: Urban green space can improve the health level of middle-aged and older adults by improving air quality.

3. Materials and methods

3.1. Regional characteristics

China is located on the west coast of East Asia and the Pacific Ocean, with a land area of about 9.6 million square kilometers and more than 18,000 kilometers of coastline. China has highly complicated geographical and ecological characteristics. This area has forests, shrubs, alpine vegetation, and aquatic and other vegetation types. It is one of the largest biodiversity countries in the world and has the second wealthiest plant population (57). There are tropical forests and seasonal rainforests in the eastern monsoon region, subtropical evergreen broad-leaved forest. Deciduous broad-leaved forest in warm temperate zone. And coniferous and broad-leaved mixed forests in temperate zone. There are coniferous forests in the cold zone. Regional vegetation spans a wide range of latitude and longitude (58), including unique plateau vegetation and altitude spectrum of several peaks on the Qinghai-Tibet Plateau (59). According to the data of the World Bank, the proportion of forest area in China increased from 18.85 to 23.43% from 2000 to 2020 and increased year by year during the inspection period, with a growth rate of 24.30%, which is relatively high. The proportion of forest area in the world is about 31% in 20 years, about 10% higher than that in China. The proportion of forest area in developed countries has remained unchanged for many years, with the United States at about 33%, Britain at about 12%, and Japan at about 68%, which has been in a reasonably high proportion range worldwide. Generally speaking, the green forest area is relatively large, but the proportion of green forest area still has room for improvement compared with developed countries in China.

Due to the geographical and climatic advantages, China's parks and green spaces have developed well. The China Municipal Government is committed to improving the urban ecological environment, hoping to beautify the urban living environment and provide recreational places for residents by expanding urban green spaces. In recent 10 years, the area of urban green space in China has obviously expanded with the efforts of the China Municipal Government.

In this study, the samples of 221 prefecture-level cities in China are selected as the objects of investigation. Figure 1 shows each selected city sample's per capita green area in 2013, 2015, and 2018. From the time trend, the number of residential green areas in cities in China is increasing, and the number of cities in the range of 2–4 square meters is increasing, too. Specifically, in 2013, there were many deficiencies in the samples, and the urban per capita green area was mainly within the range of 0–8 square meters, and the residential green area in the eastern coastal areas was higher than that in the central and western regions, and the per capita green area in a few northern cities reached the range of 8–30 In 2015, cities' per capita green area increased significantly compared with that of 2013. The number of cities in the 0–2 square meters range increased significantly, and those in the 4–8 square meters increased. The per capita green area of very few cities reached 8–30 square meters. In 2018, the number of investigation samples has increased significantly, and more cities have entered the range of about 10 square meters. What is gratifying to us is that the number of cities in the range of 2–4 square meters has reached the highest in the three investigation years.

3.2. Demographic characteristics

According to the sixth national population census, 83.15% of the older adults consider themselves healthy and basically healthy, and 16.85% consider themselves in poor health. In 2015, the fourth survey on the living conditions of the older adults in urban and rural areas of China showed that 75.24% considered themselves to be healthy or average, and 24.76% considered themselves to be in poor or very poor health. According to the Health China Action Promotion Committee, in 2018, about 8.3 older adults lived with diseases in China, and there were 180 million older adults with one or more chronic diseases, accounting for 75%. China's implementation of the strategy of actively responding to population aging has entered the fast lane. More and more studies have realized that healthy aging is the only way for China to actively cope with the aging population, and solving health problems can basically resolve the negative effects of aging.

Micro-individual data in this paper come from 2013, 2015, and 2018 follow-up surveys of China Health and Retirement Longitudinal Study (CHARLS data source: https://charls.charlsdata.com/), which is

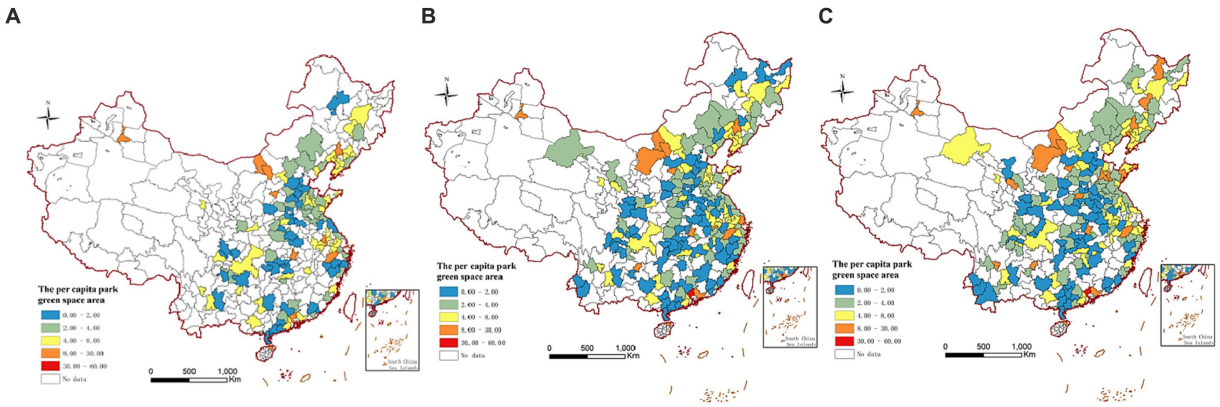

FIGURE 1
Per capita green area of China city. **(A)** 2013; **(B)** 2015; **(C)** 2018. The standard map production is based on the standard map service website of the Ministry of Natural Resources, with the approval number of GS (2019) No.1822. And, no changes to the base map boundary.

a national sampling survey project sponsored by the National Development Research Institute of Peking University. CHARLS aims to collect a set of high-quality micro-data representing the families and individuals of middle-aged and older adults aged 45 and above in China to analyze the problem of population aging in China and promote interdisciplinary research on aging. CHARLS data is collected every 2–3 years. The baseline survey in 2011–2012 covered 28 provinces, 150 counties, and 450 villages (communities) in China, involving 17,708 people from 10,257 families. Three follow-up surveys were conducted in 2013, 2015, and 2018. The study mainly includes essential personal characteristics, health status and function, pension, family income, and other information. By the time the national follow-up visit was completed in 2018, the sample had covered 19,000 respondents from 12,400 households, which can fully reflect the overall situation of middle-aged and older adults in China. At present, it has been widely used in residents' economic, social, and health research.

3.3. Data processing

Considering the lack of cities in the initial stage of inclusion and the problem of matching with CHARLS, this paper selects the data of urban green space, air quality, and high-temperature weather from 2013 to 2018 in the yearbook for analysis and according to the city code and year, the China Urban Construction Statistical Yearbook was merged with the CHARLS database. Then the missing cases were deleted by state, and finally, the micro-individual samples covering 221 cities (autonomous) regions were matched.

3.4. Measurement and selection of indicators

3.4.1. Dependent variables

Based on referring related research (60), the health status of middle-aged and older adults is measured from two dimensions: physical health and mental health, including physical illness and depression. Physical diseases are characterized by the total number of chronic diseases: "digestive diseases, kidney diseases, lung diseases, liver diseases, arthritis, asthma, diabetes, dyslipidemia, hypertensive neurological diseases" and acute diseases: "heart disease, stroke, cancer" in the CHARLS questionnaire. Each condition counts as one point, and the higher the score, the worse the physical health. Depressed mood was used to evaluate the mental health of the interviewees by designing eight adverse emotional problems and two positive emotional problems according to the depression scale (CES-D) in the CHARLS questionnaire and their feelings and behaviors last week. The issues cover (1) I am troubled by some trivial matters. (2) I find it difficult to concentrate on my work. (3) I feel depressed. (4) I find it hard to do anything. (5) I feel scared. (6) I feel lonely. (7) I do not sleep well. (8) I do not think I can continue my life. (9) I am full of hope for the future. (10) I am delighted. Calculating the score according to the respondents' answers, and the higher the score gets, the worse the mental health is.

3.4.2. Independent variables

Urban green space is the independent variable of this study, and the per capita park green space area is selected to represent it.

3.4.3. Control variables

Because residents' health will be influenced by individual characteristics, family characteristics, and living habits, this study draws lessons from previous studies on a health level. It introduces 12 indicators, including age, gender, marriage, smoking, family income, expenditure, and whether toilet facilities are available, etc. as control variables. The meanings and descriptive statistics of the main variables are shown in Table 1.

3.4.4. Mechanism variables

At present, there are few kinds of literature about the channels through which urban green space affects the health of middle-aged and older adults. Based on the above mechanism, extreme temperatures become more frequent, intense, and common under climate change, which may affect individuals' physical and mental health and cause negative emotions such as anxiety and psychological stress (61). The research will focus on the micro-mechanism of urban green space's impact on middle-aged and

TABLE 1 Meaning and descriptive statistics of main variables.

Variables	Symbol	Definition	Meaning and assignment of variables	Mean	SD
Dependent variables	*PHS*	Physical illness	0→13, the higher the score, the worse the physical health	1.6792	1.6823
	DEP	Depressive mood	0→30, the higher the score, the worse the mental health	7.7371	6.1276
	BOD	Body function	6→24, the higher the score, the worse the body motor function	8.2493	3.2691
Independent variables	*GRE*	Per capita Park green area square meters/person	Total Park green area/total population	3.5599	3.8095
	COV	Green coverage rate of built-up area	Green coverage area/urban built-up area *100%	40.7080	5.6955
Control variables	*AGE*	Age	The age of the interviewee in that year (years old)	61.0612	10.1041
	GEN	Gender	Male = 0; Female = 1	0.5208	0.4996
	MAR	Marriage	Cohabitation, married = 1; Unmarried, separated, divorced, widowed =0	0.8631	0.3438
	REG	Town and country	Living in rural areas =1, urban =0	0.5884	0.4921
	EDU	Degree of education	1→10, the higher the score, the higher the education level	3.4086	1.8759
	SLE	Average daily sleep time last month	Average daily sleep time in last month (h)	6.3157	1.8930
	HEA	Childhood health	1→5, the higher the score, the worse the physical health	2.6835	1.1155
	DRI	Frequency of drinking last year	0→9, the higher the score, the higher the frequency	1.6281	2.7451
	SMO	Smoke	Smoking = 1; No smoking = 0	0.4273	0.4947
	CHI	Number of children	Number of children raised by families (number)	2.6129	1.3987
	EXP	Household expenditure	The total amount of household expenditure is logarithm	12.6033	5.7577
	TOI	Use toilet equipment	Yes = 1; No = 0	0.0204	0.1415
Mechanism variables	$PM_{2.5}$	Air quality	Annual average value of $PM_{2.5}$	47.6436	17.6996
	TEM	Highest temperature	The annual extreme maximum temperature is Celsius	38.0509	1.5722

older adults' health from extremely high-temperature weather and air quality changes. Because urban green space helps to reduce the surface temperature and reduce the heat island effect. This can prevent residents from being in high-temperature environments for a long time and reduce the risk of heatstroke and other diseases related to high temperatures. Therefore, the annual extreme maximum temperature of Celsius is selected as a measure index to measure high-temperature weather, and the influence mechanism of urban green space on the health status of middle-aged and older adults is discussed. In addition, urban green space can effectively absorb pollutants in the air, reduce suspended particles in the air and improve air quality, which is conducive to reducing the risk of respiratory diseases for residents. Therefore, the average concentration of $PM_{2.5}$ is selected as an index to measure the air quality, and the influence mechanism of urban green space on the health of middle-aged and older adults is measured.

4. Research design

4.1. Construction of regression model

The regression model of middle-aged and older adults' health and urban green space was built by stata16 software. Because the scores of provincial diseases and depression were continuous variables, multiple

linear regression was selected to analyze the impact of urban green space on middle-aged and older adults' health. This paper focuses on the direct relationship between urban green space and middle-aged and older adults' health level. In order to more accurately study this direct causal relationship, the following measurement model is constructed to verify:

$$Y_{ict} = \alpha + \beta GRE_{ct} + \delta X'_{ict} + \varepsilon_{it} \quad (1)$$

Among them, *i* means the respondent, *c* means the city where the respondent is located, and *t* represents the year. Y_{ict} represent the mental health and physical health variables at the individual level, and GRE_{ct} means the urban green space variables in the city where the interviewee is located in, X'_{ict} indicates the control variables that may affect the health level. And, ε_{it} is a random error term.

5. Analysis of empirical results

5.1. Benchmark regression results

The effects of urban green space on middle-aged and older adults' physical and mental health were investigated by regression method. The dependent variables in columns (1)–(4) of Table 2 are the physical health and mental health of middle-aged and older adults, respectively. In order to reduce the estimation bias caused by missing variables, we control the individual characteristics and family characteristics of middle-aged and older adults, respectively. Among them, The columns (1) and (3) indicate the control of individual level control variables, and columns (2) and (4) indicate the control of individual and family level control variables. It can be found that the estimation coefficients are −0.0167, −0.0171, −0.0657, and −0.0623, respectively, and all of them have passed at least 5% significance level test, indicating that the increase of per capita green park space will significantly reduce the scores of physical diseases and depression, that is, urban green space can effectively improve the physical health and mental health of middle-aged and older adults.

TABLE 2 Benchmark regression results.

Variables	(1)	(2)	(3)	(4)
	PHS	PHS	DEP	DEP
GRE	−0.0167***	−0.0171***	−0.0657**	−0.0623***
	(−3.4646)	(−3.2282)	(−2.4634)	(−2.6456)
Individual controls	YES	YES	YES	YES
Family controls	NO	YES	NO	YES
_cons	−1.0708***	−1.0002***	12.1694***	12.4092***
	(−6.4151)	(−4.8897)	(22.9142)	(20.1335)
N	25,256	25,210	24,932	24,892
R^2	0.1221	0.1259	0.1359	0.1385

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

5.2. Robust test

5.2.1. Replacing independent variable

In order to increase the reliability of the research conclusion, the green coverage rate of the built-up area is used to reflect the urban green space level of the city (district) under its jurisdiction, and the specific results are shown in columns (1)–(4) of Table 3. It can be seen that the estimation coefficients are all negative, and the green coverage rate of the built-up area substantially reduces the physical diseases of the older adults, indicating that the improvement of the green coverage rate of the built-up area will significantly improve the health status of middle-aged and older adults. The robustness of the benchmark regression mentioned above is proved. When the individual and family control variables are not added, the influence of urban green coverage on the depression of older adults is significantly harmful. In contrast, the improvement of urban green range on the depression of more senior people needs to be further verified after adding various control variables.

5.2.2. Replacing dependent variable

In order to increase the rigor of the research conclusion, this paper measures the health status of middle-aged and older adults with physical function indicators, covering the following six problems: it is difficult to lift or carry heavy objects weighing more than 10 kg, it is challenging to reach arms above shoulders, it is difficult to bend over, kneel or squat down, it is tough to climb several stairs without rest, it is difficult to stand up from a chair after sitting for a long time, and it is difficult to pick up a small coin from a table. Respondents answered "I do not have any difficulties" = 1; "It's a little difficult but it can be done" = 2; "I am in trouble and need help" = 3; "I cannot do it" = 4, and the scores of 6 questions add up to the physical function score. The higher the score gets, the worse the health status is. As the score of physical function is a continuous variable, a multiple linear regression model is used to estimate it, and the specific results are shown in columns (1)–(3) of Table 4. It can be seen that the estimation coefficients are all significantly negative at the level of 1%, indicating that the increase of per capita park green area substantially reduces the score of physical function. That is, urban green space effectively improves the health status of middle-aged and older adults, which proves the robustness of the previous benchmark conclusions.

5.2.3. Shorten the time window

In order to further test the robustness of the benchmark conclusion, the number of samples in 2013 and 2015 was excluded, and the newer time data, namely the sample data in 2018, was selected for the robustness test. The results are shown in Table 5. After controlling the variables of individual and family characteristics, respectively, the estimation coefficient is significantly negative, and the increase of per capita park green area substantially reduces the scores of physical illness and depression, which is consistent with the benchmark conclusion and passes the robustness test.

5.2.4. Data trimming and addition of control variables

In order to test the reliability of the impact of urban green space on the health of middle-aged and older adults, tail-shrinking continuous variables. That is, the continuous variable was simplified by 1% bilateral

TABLE 3 Replace the independent variable for robustness test.

Variables	(1)	(2)	(3)	(4)
	PHS	PHS	DEP	DEP
COV	−0.0111**	−0.0117**	−0.0418**	−0.0408**
	(−2.2582)	(−2.3479)	(−1.9963)	(−2.0086)
Individual controls	YES	YES	YES	YES
Family controls	NO	YES	NO	YES
_cons	−0.6791**	−0.6037**	13.6373***	13.7860***
	(−2.4374)	(−2.0283)	(13.9488)	(13.4559)
N	25,259	25,213	24,935	24,895
R^2	0.1221	0.1260	0.1358	0.1385

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 4 Replace the dependent variable for robustness test.

Variables	(1)	(2)	(3)
	BOD	BOD	BOD
GRE	−0.0344***	−0.0197***	−0.0173***
	(−3.0395)	(−3.2100)	(−2.9716)
Individual controls	NO	YES	YES
Family controls	NO	NO	YES
_cons	8.0992***	4.2695***	4.7250***
	(99.5053)	(16.4364)	(17.6046)
N	33,013	24,597	24,555
R^2	0.0064	0.1811	0.2116

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 5 Shorten the time of sample inspection window for robustness test.

Variables	(1)	(2)	(3)	(4)
	PHS	PHS	DEP	DEP
GRE	−0.0183***	−0.0184***	−0.0613*	−0.0563**
	(−3.6849)	(−3.5844)	(−1.9249)	(−2.0230)
Individual controls	YES	YES	YES	YES
Family controls	NO	YES	NO	YES
_cons	0.0729	0.1715	13.0092***	13.3966***
	(0.3409)	(0.6181)	(22.3469)	(19.2282)
N	11,982	11,968	11,703	11,692
R^2	0.0959	0.1004	0.1314	0.1353

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

contraction. The results are shown in Table 6. The regression coefficients were all significantly negative. In addition, because of the macro factors of the city, it may also have a certain impact on the health of residents. Here, this paper returns after examining the factors of urban meteorology, economy, medical care and industrial structure. Specifically, climate characteristic is measured by average temperature, urban economic development level is measured by logarithm of urban real GDP, medical level is characterized by logarithm of urban beds, and industrial structure is measured by the proportion of the added value of tertiary industry to the added value of secondary industry. The regression results are shown in columns (5) and (6), and the results are still robust after adding macro variables.

5.3. Heterogeneity test

This study is based on the differences in respondents' gender, age, marital status, education level, residence (urban or rural), geographical location (eastern, central, and western regions, north and south), and park distribution (62) to test the heterogeneity of group regression.

5.3.1. Heterogeneity effect across gender

According to the gender differences of respondents, the heterogeneous effects of male and female respondents affected by urban green space were tested, respectively. The results in columns (1)–(4) in Table 7 respectively report the influence coefficient of per capita green space area on the physical illness and depression of male and female samples. It is observed that the improvement of per capita green space area on females physical illness is slightly better than that of males, and the increase of per capita green space area can improve the enthusiasm for male outdoor activities or physical exercise, thus improving the physiological health effect brought by per capita green space area. However, the per capita green area is more significant for female to improve their depression, which may be due to the influence of China's traditional lifestyle of "males are outside, and females are inside." Females have relatively sufficient time for leisure and entertainment, and the external environment, such as green parks, easily influences their mood and mental health. Therefore, the per capita green area has a more significant mental health effect.

5.3.2. Heterogeneity effect across age

According to the heterogeneity of age, the respondents were divided into two sample groups: those over 60 and those under 60. Columns (1)–(4) of Table 8 report the results of group regression based on age heterogeneity: urban green space area has a more apparent inhibitory effect on physical diseases and depression of the older adults over 60 years old. The possible reason is that, on the one hand, research shows that older adults are more sensitive to external environmental health than younger people (63). On the other hand, due to retirement and other reasons, the older adults will increase their outdoor leisure time, which will positively promote their health, improve their social participation, increase social support, and improve cohesion of the community. Therefore, the per capita green space area has more pronounced effects on the physical health and mental health of the older adults over 60 years old (64). The working hours of middle-aged people under the age of 60 occupy a more significant part of their lives. At this time, the marginal inhibitory effect of urban green space on physical diseases and depression is significantly reduced.

5.3.3. Heterogeneity effect across education level

According to their actual years of education, the interviewees are divided into those who have completed 9-year compulsory education and those who have not. The results in Table 9 show that the per capita

TABLE 6 Data trimming and addition of control variables for robustness test.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	PHS	PHS	DEP	DEP	PHS	DEP
GRE	−0.0196***	−0.0205***	−0.0809***	−0.0765***	−0.0193*	−0.0631**
	(−3.4933)	(−3.3769)	(−2.7390)	(−2.8841)	(−1.7133)	(−1.9812)
Individual controls	YES	YES	YES	YES	YES	YES
Family controls	NO	YES	NO	YES	YES	YES
_cons	−1.0474***	−0.9694***	12.5202***	12.7560***	−1.4895***	15.1240***
	(−6.1536)	(−4.6452)	(23.8374)	(20.1010)	(−3.5362)	(7.4091)
N	25,256	25,210	24,932	24,892	24,976	24,654
R^2	0.1240	0.1278	0.1392	0.1418	0.1353	0.1406

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 7 The result of based on gender heterogeneity.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	Male		Female	
GRE	−0.0208***	−0.0528**	−0.0134***	−0.0684**
	(−3.0029)	(−2.3552)	(−2.8322)	(−2.5526)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−1.1175***	10.8578***	−0.6968***	15.5867***
	(−4.7525)	(16.0437)	(−2.9095)	(20.4314)
N	12,147	12,021	13,063	12,871
R^2	0.1156	0.0926	0.1330	0.1319

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

green space area is somewhat influenced by the heterogeneity of education level. By observing the regression coefficient, we know that urban green space can significantly reduce the physical illness and depression of the older adults regardless of their low education level or high education level, and it significantly promotes physical health and mental health. However, this positive impact is more significant in the samples with high education levels. Some scholars believe that the difference in education level is the root cause of the health gap, and education can improve health by improving an individual's internal function and living ability, which helps develop social and psychological resources (65).

5.3.4. Heterogeneity effect across marital status

According to the marital status of the respondents, they are divided into married and non-married. Columns (1)–(4) of Table 10 report the results of heterogeneous regression analysis based on marital status. For married people, the positive effect of urban per capita green space areas on psychological and physical health is more apparent, and the effect on physical illness and depression is significantly harmful. However, it does not significantly affect middle-aged and older adults in non-married status. The possible reason is that married or cohabiting middle-aged and older adults are more willing to increase their outdoor entertainment time with the company of their families. A stable and secure relationship is very important (66), and at the same time, their health status will be significantly improved. In contrast, middle-aged and older adults in non-married status feel more lonely because of the lack of family companionship, and negative emotions cannot be resolved in time under the comfort of family members (67). This has caused long-term depression, and it is difficult to have a positive impact through the per capita green space area of the city.

5.3.5. Heterogeneity effect across urban and rural areas

According to the urban-rural classification variables provided by CHARLS, based on the National Bureau of Statistics data, all the respondents were divided into urban areas and rural areas for sub-sample regression. Columns (1)–(4) in Table 11 report the results of the grouping test based on the heterogeneity of urban and rural areas. The results show that the effect of green space in rural areas on reducing physical diseases and emotional depression of the older adults is higher than that in urban areas. For this result, we give a reasonable explanation: each city's number of parks and green spaces per capita is minimal. At the same time, due to the rapid development of urbanization, the enjoyment of green spaces by urban residents has been severely squeezed, and the developed transportation system has brought severe environmental pollution problems, resulting in the availability of barrier-free green spaces such as parks and forests in urban areas is often worse than that in rural areas (68). Therefore, the positive effect of green space on improving the physical and mental health of the older adults is more significant in rural areas.

5.3.6. Heterogeneity effect across regional

According to the economic development of the interviewee's region, the interviewee's region is divided into the eastern, central, and western regions for heterogeneity test. Table 12 (1)–(6) reports the results of the heterogeneity test based on the grouping regression of the eastern, central, and western regions. It is found that urban green space has a more noticeable impact on the health of middle-aged and older adults in the eastern region, and can significantly alleviate the physical illness and depression of older adults in the eastern region. However, it has no significant impact on the health of middle-aged and older adults in the western and central regions. The possible reason is that the economic development level in the eastern region is

TABLE 8 The result of based on age heterogeneity.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	>=60		<60	
GRE	−0.0238***	−0.0639**	−0.0066	−0.0593**
	(−5.4167)	(−2.5494)	(−1.2157)	(−2.4677)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	1.6027***	11.6442***	1.2468***	12.7072***
	(8.4357)	(18.5822)	(7.7511)	(18.2035)
N	13,373	13,122	11,904	11,836
R^2	0.0769	0.1324	0.0635	0.1460

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 9 The result of based on the heterogeneity of education level.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	Higher education level		Low education level	
GRE	−0.0192***	−0.0727***	−0.0149**	−0.0672**
	(−3.4353)	(−4.0712)	(−2.3425)	(−2.2619)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−1.0453***	11.3259***	−0.8897***	10.4367***
	(−3.5194)	(13.2329)	(−4.5434)	(15.6741)
N	7,865	7,818	17,345	17,074
R^2	0.1197	0.1153	0.1338	0.1214

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 10 The result of based on the heterogeneity of marital status.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	Married		Non-married	
GRE	−0.0193***	−0.0794***	−0.0032	0.0530**
	(−3.6483)	(−3.2453)	(−0.4262)	(2.0959)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−1.1432***	10.5319***	0.3118	15.9082***
	(−5.5485)	(18.5565)	(0.7744)	(10.4010)
N	21,956	21,730	3,254	3,162
R^2	0.1302	0.1346	0.0984	0.1172

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 11 The result of based on the heterogeneity of urban and rural areas.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	Rural		Uran	
GRE	−0.0216*	−0.1226***	−0.0143***	−0.0264**
	(−1.9082)	(−3.0845)	(−3.6951)	(−2.0620)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−0.6611***	12.5992***	−1.3853***	13.3708***
	(−2.6465)	(16.9657)	(−5.1093)	(16.4081)
N	14,968	14,770	10,242	10,122
R^2	0.1162	0.1372	0.1433	0.1165

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

higher than in the western and central regions, and the residents' demand for urban greening has increased. The economically developed cities in China are more concentrated in the eastern coastal cities, and the acceleration of urbanization has caused "urban diseases" and air pollution (69), which is harmful to the physical and mental health of the older adults.

5.3.7. Heterogeneity effect across north and south

Taking the Qinling-Huaihe River as the boundary, the respondents' location is divided into the south and the north, and the results of the grouping regression heterogeneity test are reported in columns (1)–(4) of Table 13. It can be seen that the impact of urban green space on the health of middle-aged and older adults in the southern region is significantly higher than that in the northern region. The possible reason is that the air pollution level in the north is higher than that in the south, and the increase of urban green space area will significantly improve air quality and increase people's outdoor travel time, thus improving people's health.

5.3.8. Heterogeneity effect across park quantity distribution

Because the appeal study cannot fully reflect the influence of the heterogeneity of urban parks on the health of the older adults, this paper makes a heterogeneous group regression analysis based on the number of urban parks. Specifically, the average number of urban parks is obtained nationwide, and cities with more than or equal to the average number of urban parks are regarded as the group with more parks; on the contrary, cities with less than the average number of urban parks are regarded as the group with fewer parks. A more significant number of urban parks means that the distribution of urban parks is more dispersed, while a smaller number of parks means that the publication of urban parks is more concentrated. The results of heterogeneous regression are shown in columns (1)–(4) of Table 14. The results show that in the areas where the number of urban parks is less, that is, if the distribution of urban parks is more concentrated, urban green space can improve the physical illness and depression of the older adults better. The possible reason is that the distribution in

TABLE 12 The result of based on regional heterogeneity.

Variables	(1)	(2)	(3)	(4)	(5)	(6)
	PHS	DEP	PHS	DEP	PHS	DEP
	Eastern		Central		Western	
GRE	−0.0101*	−0.0324*	−0.0192	−0.0734	−0.0188	−0.0272
	(−1.9058)	(−1.7811)	(−1.0066)	(−1.3015)	(−0.9959)	(−0.4264)
Individual controls	YES	YES	YES	YES	YES	YES
Family controls	YES	YES	YES	YES	YES	YES
_cons	−1.0296***	12.0424***	−1.0656***	12.5742***	−0.3133	14.1821***
	(−3.8038)	(15.3862)	(−3.3140)	(12.3425)	(−0.8263)	(10.8848)
N	11,314	11,155	8,389	8,296	5,501	5,435
R^2	0.1339	0.1293	0.1148	0.1236	0.1295	0.1736

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 13 The result of based on the heterogeneity of north and south regions.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	North		South	
GRE	−0.0119**	−0.0526***	−0.0322***	−0.1170**
	(−2.5992)	(−3.2677)	(−2.6493)	(−2.0839)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−0.7898***	12.6221***	−0.7761**	11.1593***
	(−2.9091)	(18.2760)	(−2.2514)	(8.3931)
N	12,765	12,581	11,456	11,330
R^2	0.1294	0.1366	0.1343	0.1457

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

urban parks is more concentrated, which to some extent reflects the larger scale of parks, perfect infrastructure, and good planning of park entertainment and fitness functions. The effect of air purification and noise isolation produced by green vegetation is more pronounced, and larger and more concentrated urban green spaces can have an excellent positive effect on the health of the older adults.

6. Mechanism test

There are few pieces of literature about the channels through which air pollution affects the health of middle-aged and older adults. Based on the mechanism discussion above, the micro-mechanism of the impact of urban green space on the health of middle-aged and older adults will be analyzed from the changes in extremely high-temperature weather and air quality. The annual extreme highest temperature of Celsius is used as an index to measure high-temperature weather, and the annual average value of $PM_{2.5}$ is used as an index to measure air quality to measure the impact mechanism of urban green space on the health of middle-aged and older adults. The results are shown in Table 15. It is found that the increase of urban green space area significantly reduces the extreme maximum temperature and air pollution level. Specifically, for every square meter of green park space per capita, the annual extreme highest temperature decreases by 0.0694°C, and the annual average value of $PM_{2.5}$ decreases by 0.5236 because urban green space helps to reduce the surface temperature and the heat island effect. This can prevent residents from being in a high-temperature environment for a long time and reduce the risk of heatstroke and other diseases related to high temperature. In addition, urban green space can effectively absorb pollutants in the air, reduce suspended particles in the air and improve air quality, which is conducive to reducing the risk of respiratory diseases for residents. At the same time, green plants have a calming effect on people's psychology so that the central nervous system can easily adjust and improve the body's function, giving people a feeling of tranquility, comfort, vitality, and spirit, thus improving their mental health. Moreover, increasing urban green space areas can further alleviate people's nervous and depressed moods, and reduce the secretion of adrenaline and the excitability of human sympathetic nerves to a certain extent, thus reducing people's mental stress. To sum up, the study found that the positive impact of urban green space on the health of middle-aged and older adults is mainly conducted by reducing the annual highest temperature and the annual average value of $PM_{2.5}$, which is consistent with the hypothesis of the mechanism discussion mentioned above.

7. Discussion

Based on the incidence data of acute and chronic diseases and the depression scale of the older adults in the China Health and Retirement Longitudinal Study (CHARLS), this study considered the health status of the older adults in China from physical and psychological perspectives. On this basis, matching the data of urban per capita green space areas, this paper discusses the influence of urban per capita green space areas on the physical illness and depression of the older adults. It tests the mechanism path behind the influence of urban per capita green space areas on the physical and mental health of the older adults. The results show that the increase of urban per capita green areas can significantly improve the physical and mental health of the older adults. Compared with the previous research results, it is found that some studies believe

TABLE 14 The result of based on the heterogeneity of park quantity distribution.

Variables	(1)	(2)	(3)	(4)
	PHS	DEP	PHS	DEP
	More parks		Fewer parks	
GRE	−0.0030	−0.0349***	−0.0464***	−0.1591***
	(−0.4908)	(−4.1298)	(−3.1501)	(−2.9396)
Individual controls	YES	YES	YES	YES
Family controls	YES	YES	YES	YES
_cons	−1.1041***	13.0794***	−0.9388***	12.1258***
	(−3.1676)	(15.1814)	(−3.9900)	(16.8437)
N	6,144	6,036	19,066	18,856
R^2	0.1304	0.1153	0.1263	0.1450

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

TABLE 15 The result of mechanism test.

Variables	(1)	(2)	(3)	(4)
	TEM	TEM	$PM_{2.5}$	$PM_{2.5}$
GRE	−0.0803***	−0.0694***	−0.5789***	−0.5236***
	(−36.6208)	(−29.6039)	(−23.1685)	(−19.8967)
Individual controls	NO	YES	NO	YES
Family controls	NO	YES	NO	YES
_cons	38.3367***	38.3523***	49.7061***	54.8864***
	(3351.3551)	(399.2156)	(381.5433)	(50.8612)
N	34,041	25,210	34,041	25,210
R^2	0.0379	0.0516	0.0155	0.0405

T value is indicated in brackets. *, **, *** represent the significance levels of 10%, 5% and 1%, respectively.

that contacting with nature has a positive impact on people's health, and the differences in the nature, size, distance, and quality of urban green space are discussed (70). Exposure to green space is associated with reducing people's stress, depression, and anxiety symptoms and increasing happiness (71). The areas and samples investigated by researchers are different, and the methods of investigation and research are also different. However, they all affirm the conclusion that urban green space can improve people's health well. Scholars' analysis of different samples shows the diverse functions of urban green spaces with different properties (72). Studying spatial differences gives us a deeper understanding of this scientific problem. This study focuses on the interaction between urban green space and the older adults and can fully understand the spatial distribution heterogeneity of per capita green space in China, providing a reference for future research and practice.

Based on verifying the health effect of urban green space, this study further explored the innovative mechanism path. High-temperature weather and air quality are the necessary mechanisms for urban green space to affect the health of middle-aged and older adults because urban green space helps to reduce the surface temperature and alleviate the heat island effect (39, 73). This can prevent residents from being exposed to high temperatures for a long time and reduce the risk of heatstroke and other diseases related to high temperatures. In addition, urban green space can effectively absorb pollutants in the air, reduce suspended particles in the air, improve air quality, and help reduce the risk of diseases among residents (74). This inspires us to help residents suffering from urban heat island effects and air pollution and provides an operable mechanism for improving the health status of sub-healthy people.

Although this study clarifies the relationship between urban per capita green space area and physical and mental health of the older adults, it is inevitable that there are some limitations. First of all, there are some limitations in the use of health data in this study. We have not obtained the health data of the older adults after 2018. It may not be comprehensive enough to study the influencing mechanism path only from air pollution and urban extreme temperature. In the future, we will further test the healthier effects of urban green space, such as social contact and social cohesion; Secondly, the impact of urban green space on improving the health status of the older adults may show a dynamic feature in stages with the progress of time. Future research can distinguish the long-term and short-term effects of urban green space on health and conduct discussion and research in stages. Finally, the number of per capita areas may be difficult to reflect the impact of the spatial distribution of urban green space on people's health. In the future, we will consider using spatial analysis method to accurately locate the distribution of urban parks and do further research, which will also become one of the schemes to optimize the quality of urban green space. Moreover, combining provincial, municipal and county-level data, and discussing in depth the influence on the health level of the middle-aged and older adults from a macro perspective, which is one of the future research focuses.

8. Conclusion

This study used data from the China Health and Retirement Longitudinal Study (CHARLS) in 2013, 2015, and 2018 to explore the causal relationship between urban green space and the health of middle-aged and older adults. The study found that increasing urban green space areas can significantly improve the physical and mental health of middle-aged and older adults, and the robustness test confirmed the above conclusions. Heterogeneous regression analysis was conducted on the gender, age, marital status, education level, residence (urban and rural), geographical location (eastern, central, western, northern and southern regions) and park quantity distribution. It can be found that the increase of urban green space areas has a more significant impact on the health of male groups, older groups, married or cohabiting groups, and middle-aged and older adults living in rural areas, areas with high economic development levels (eastern and central regions), northern regions and parks are more concentrated. In addition, further research found that high-temperature weather and air quality are essential mechanisms for urban green space to affect the health of middle-aged and older adults, and urban green space can improve the health level of middle-aged and older adults by reducing the

temperature value of extremely high-temperature weather and improving air quality.

Data availability statement

The datasets presented in this study can be found in online repositories. The names of the repository/repositories and accession number(s) can be found at: (1) Micro-individual data in this paper come from 2013, 2015, and 2018 follow-up surveys of China Health and Retirement Longitudinal Study (CHARLS data source: https://charls.charlsdata.com/); (2) The data of urban green space, air quality, and high-temperature weather from 2013 to 2018 in the yearbook for analysis and according to the city code and year, the Statistical Yearbook of Urban Construction (Data source: https://data.cnki.net/yearBook/single? Id = N2023010064) China Environmental Statistics Yearbook (Source: https://data.cnki.net/yearBook/single? Id = N2022030234).

Author contributions

QL, YL, and LY: conceptualization and project administration. QL and JG: methodology. YL and XC: software and data curation. JG and XZ: validation. QL: writing—original draft preparation and funding acquisition. YL, LY, XC, and XZ: writing—review and editing. QL and XC: visualization. QL, YL, and XC: supervision. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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What landscape elements are needed for hospital healing spaces? Evidence from an empirical study of 10 compact hospitals

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Background: Modern medical research shows that a rationally planned landscape environment helps patients recover. With the growing number of hospital patients and the tightening of *per capita* medical landscape land, the use of limited landscape resources to serve patients has become challenging.

Methods: This study focused on the landscape environment of 10 hospitals in Guangdong Province, China. Based on the KANO theoretical model, a survey questionnaire was designed and administered to 410 participants. The data were analyzed based on demand attributes, importance, sensitivity, and group differences.

Results: The maintenance requirements were the most important item in the sensitivity ranking. Furthermore, the analysis revealed that the users need a safe, quiet, and private environment, owing to their higher requirements, including visual healing, rehabilitation activities, shading and heat preservation, and medical escort. Moreover, adolescents and older adult patients have common and contradictory environmental needs. For example, the landscape environment should provide both an active space and a quiet rehabilitation environment.

Conclusion: This study evaluates how landscape resources can be better utilized from the perspective of the user and expands the theory of healing landscapes, which has practical implications for hospital renovation and landscape environment strategies.

KEYWORDS

landscape environment, compact hospital, patient preferences, KANO model, healing property

1 Introduction

Many studies have shown that a favorable landscape environment in hospitals contributes to patient recovery (1–3). The landscape environment has become one of the most important evaluation criteria for creating modern hospitals, and its role has changed from an "accessory" to hospital buildings to a "necessity" for system planning (4–6). Currently, the landscape environment of Chinese hospitals is undergoing transformations. First, the *per capita* greenspace

rate is decreasing sharply due to the increase in the number of patients. According to statistics, the number of hospital beds in China has increased from 2.4 to 6.7 beds per 1,000 people from 2003 to 2021 and will reach 7.5 beds per 1,000 people in 2030. As of 2022, the average green space rate of the 1,629 grade-A tertiary hospital sites in China is only 22.5%, which is less than the national standard of the "Construction Standards for General Hospitals" in 2021 (the New General Hospitals green space ratio needs to be maintained at more than 35%) (7–9). Second, the expansion of medical facility spaces in hospitals is reducing the land for the landscape environment. The accelerated rate of renewal of the current medical system has led hospitals in high-density cities to sacrifice the landscape environment in exchange for the construction land available for medical facilities. A large amount of landscape environment land has been transformed for medical, ancillary, and transportation functions, which results in shrinking areas of hospital landscape environment, homogeneous space, and a reduction in the number of vegetation and species (10, 11). Third, hospital landscape environment enhancement is caught in the dilemma of unsustainable development. Planners and designers usually adopt a concessionary attitude to confront the current situation of hospital landscape constrictions without a bottom-up renewal design strategy from the perspective of the experience and healing of patients in hospitals (7, 12).

Edward Wilson, in his study Pro-Life, asserts that the human instinct to be close to the natural world, that is, "humans are naturally emotionally attached to natural lifeforms," is the theoretical origin of the tendency of human beings to have a need for healing (13). Subsequently, researchers found that human preferences for natural colors and biomorphic forms are related to the survival instinct to find food and established a systematic sub-theory for the existence of color and biophilic shape (14). The concept of therapeutic landscapes and gardens has been established in the medical field, giving rise to four major theoretical schools: (1) medical geography, (2) environmental psychology, (3) beneficial environments, and (4) horticultural therapy (5). In addition, the environmental psychology school incorporates two major theories: (1) attention restoration theory (ART), which establishes the four restorative environmental characteristics of distance, range, fascination, and compatibility (5, 15). (2) Aesthetic affect theory (AAT), which draws on the psychoevolutionary theory and establishes relief from physical symptoms, illness, or trauma, as well as relief from coping with stress, as the three characteristics of a healing garden (16). Recently, the wellness theory has been widely recognized in healthcare architecture worldwide and is centered on encouraging the 'wellness factor' in hospital design to create a restorative environment for patients (17).

At present, research on the hospital landscape environment focuses on the following three aspects: (1) the influence of the landscape environment on the recovery effect: In the early 19th century, Dr. Nightingale found that increasing the species and area of trees planted in the landscape, improving the ventilation of the environment, and choosing warm and comfortable building materials and colors helped patients' recovery. With the development and popularization of medical technology, the rate of patients' recovery and treatment has increased significantly. However, the influence of the landscape environment in medical facilities on long-term inpatients has been neglected, with studies revealing that in hospitals with poor landscape environments, patients are confronted with varying degrees of depression and lower mood during hospitalization and after recovery (6, 18, 19), (2) improvement of the medical model based on the results of psychological studies of the landscape environment: Many scholars, after realizing that the hospital landscape environment affects psychology of patients, conducted empirical studies to gradually confirm the negative impact of the "single biological" medical model in the rehabilitation stage. In the United States, the doctor Engel believes that hospitals and medical programs need to eliminate the negative impact of the medical environment on patients and proposes a new "bio-psycho-social" medical model so that the healing value of the landscape environment is back in public view, and (3) research on the influence of the landscape environment on patient healing (20, 21). Malkin proposed, while designing apartments for the older adult, that a healing environment should have five factors: natural contact, comfortable temperature, positive transfer, social support, free space, and elimination of negative environmental impacts. Empirical research has been conducted based on the five-factor framework and has gradually improved the construction of a multi-dimensional, multi-factor, and multi-level index evaluation system (22–26). Xiaodong Lan conducted virtual reality tests of probiotic indoor environments and found differences in anxiety relief processes and changes in physiological indicators of stress reflection in different age groups (27). Tijsen found that older adult populations face greater challenges in coping with the external environment during the rehabilitation process (28). The above-mentioned studies have demonstrated that extensive landscape plant environments are crucial for patient recovery and that the shaping of healing environments should be incorporated into the health and economic benefits of hospital design. The methodology used in the current study focused on qualitative research, including synthesis reviews, video statistics, participant observation, interviews, scenario mapping exercises, and technical methods using quantitative research (29–32).

Currently, there is a mismatch between the needs of patients and the supply of healing environments in China's austere hospitals. Such an imbalance between the two is due to the overcrowding of public environments by medical buildings. Studies on healthcare healing environments have mostly used conventional statistical methods, focusing on exploring potential patterns of influence, but have failed to explore the needs that are key for the patients, the priority level of their needs, and specific improvement measures, as well as the relative lack of categorization of the different age groups of the population. Therefore, this study constructs an index model of the demand for hospital landscape from the perspective of users, especially patients, proposing a planning strategy for austere hospitals to make use of the limited landscape environment to better serve users of different ages and groups through qualitative research, which expands the relevant theories and specific technical methods of the healing environment.

2 Study design

This study establishes a two-dimensional cognitive model of the satisfaction status of the demand characteristics of the landscape environment and the degree of satisfaction of the user group using KANO theory. This theory was proposed by the Japanese Professor Noriaki Kano in 1984, inspired by Herzberg's two-factor theory, and was mainly applied to product development and optimization in the early stages of its birth. The KANO two-dimensional model aims to

set up positive and negative questions by the same requirement type, that is, the change in respondents' satisfaction when having and not having, and to determine the belonging requirement type by quantitative calculation to assist management decisions. Current KANO research is focused on three major areas: (1) theoretical research to optimize the quantitative statistical methods for each quality attribute of the KANO model (33); (2) practical areas that are widely used in various processes such as product development, production, sales, and promotion to improve the satisfaction of the user group (34, 35); (3) interdisciplinary studies combining with environmental behavior, psychology, sociology, and other disciplines to perform multiple types of demand analysis, such as Chen, Yao, and Lee applied the KANO model to conduct service demand classification studies on urban riverbanks, suburban mountainous areas, urban parks, pedestrian streets, and other recreation area environments, to develop types of services to enhance tourist satisfaction (36, 37).

Fernando used the KANO model to evaluate the quality of healthcare services in Peruvian public–private partnerships with health institutions and concluded that patients have a need for service interaction experiences (38). Rodrigues de Vasconcelos synthesized a KANO model with a balanced score card to tap into the tendency of patient satisfaction in a Brazilian public hospital, improving patient adherence indicators for treatment (39). Lujie Deng collected data from 300 users for the hospital signage system at Guangzhou Hospital, which ultimately reflects the functional requirements (40) of digital intelligence and regional culture. The above studies show that the KANO model has a wide range of applications in hospital service quality improvement and is also applicable to the study of healing environments. The strengths of the hospital healing environment need to be studied through the KANO model, including: (1) a two-dimensional assessment of the importance of environmental needs, both positive and negative, for all environmental user groups, especially patients, reducing subjective misjudgments by respondents to a one-way question. (2) When hospital landscape environment modification fails to meet the needs of a variety of users, the prioritization of needs can be quickly identified, with the first priority being to meet core needs (41). (3) The KANO model can be combined with research tools, such as AHP, QFD, and FIE, which can continue to expand the depth of research in hospital healing environments (39, 42).

The technical route of the research first establishes a composite evaluation index system by identifying demand attributes, sets up a KANO model demand questionnaire corresponding to them individually, and determines whether the content of the questionnaire is comprehensive and clear through preliminary research. Second, the results of the data obtained from this research were classified into demand types for the first time. Finally, secondary classification and evaluation of the need types were conducted by calculating the importance, sensitivity, relative weight, and difference in each index demand (Figure 1).

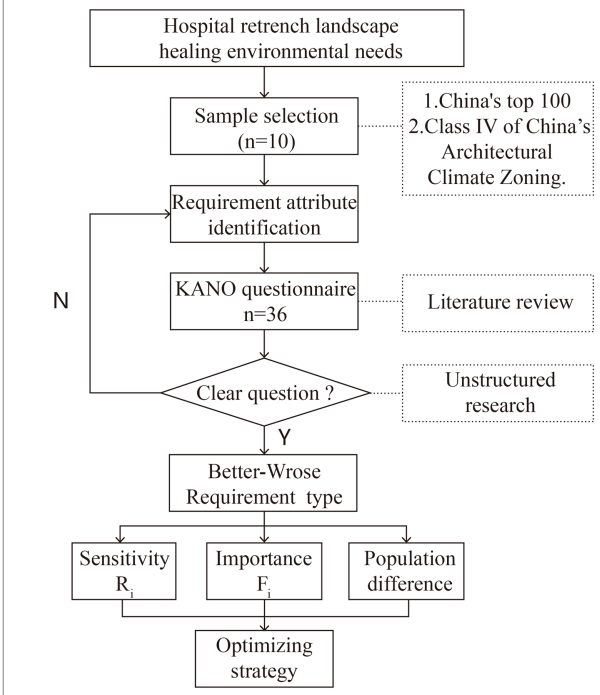

FIGURE 1
Study design.

2.1 Study sample

The Fudan edition of the "Top 100 Chinese Hospitals in 2022" is based on the methodology of the American Best Hospitals Ranking Specialist Reputation Assessment, in which the quality of hospitals depends on the authority and dedication of the reviewing experts and is fully recognized by medical units, doctors, and patients. To reduce the differences in the needs of users for healing environments in different geographic and climatic environments, 10 studies selected 10 hospitals as research objects in the Class IV hot summer and cold winter areas of China's Architectural Climate Zoning. The 10 selected hospitals were all located in an urban center. From the on-site research, it can be seen that seven of the hospitals are still in a state of expansion and reconstruction within the limited land. Their average building density reaches 43% and is higher than the national quartile level of 35%; the average green space rate is only 15%, which is lower than China's construction standard of 25%; and the average plot ratio of 10 hospitals is 4.07. However, sufficient public space provides conditions for shaping the natural environment, and the greenspace area is one of the most important indicators of the green environment of hospitals. The greenspace ratio is one of the most important indicators of green environments in hospitals. Pakzada, Osmonda, and Corkery's study of the Green Infrastructure Performance Assessment Framework (GIPAF) model focused on the interactions between human health and urban ecosystems, including the provision of outdoor activities and green space as key indicators (43). Hui Dang and Jing Li evaluated the esthetic value of urban green ecological landscapes by using multi-optical remote sensing to calculate the green space rate index, and the integration of indicators proved that population health and the perception of urban green space landscapes cannot be ignored (44). The 10 samples selected for this study reflect the characteristics of austere hospitals in terms of building density and greenspace ratio, which are representative of the study (Supplementary Table S1).

2.2 Setting of the research questionnaire

2.2.1 Factors

Currently, research on healing landscapes involves many disciplines, such as landscape, psychology, sociology, and management, with a comprehensive set of evaluation indicators not yet established. Eliane and Layla used machine learning techniques and regression analysis to determine the relationship between the physical environment of the ward and patient health and found that spatial comfort, safety, autonomy, and self-happiness had a strong influence (45). Karin conducted a healing environment review study in which only 30 out of more than 500 relevant influences were found to have significant effects that could be included in the evaluation criteria, with positive effects in terms of sunlight, air, and location, and differences in the degree of interventions for multiple stimuli such as sound, nature, and television (46). Jody and Woo-Hwa conducted an evidence-based design of healing landscapes, combining 61 healthcare staff empirical studies to uncover landscape preferences such as private spaces, landscaped paths, garden benches, and stream landscapes that are conducive to soothing healthcare work stress (47). Fouad performed a quantitative analysis of the psychological preferences of 148 patients in a post-use evaluation study in a general hospital and revealed that patient satisfaction was positively correlated with space appearance, comfort control, privacy environment, and pleasant healing environment, while age and education were negatively correlated (48). Morales, J. Van, in a study of 798 studies, tapped the positive factors of the physical environment in the rehabilitation process, where security and privacy, clean and comfortable, controlled space, and humanistic care were positive factors for patients and families, whereas environmental comfort, room functionality, and technical support were important factors for staff (49). Patrick, Timothy, and Mukaddes, in their study of therapeutic environments for patients with Alzheimer's disease, found that rehabilitation exercises, sensory stimulation, mental mapping, shaded and sheltered spaces, as well as security maintenance, had varying degrees of positive effects on patients (50). Stephen's quantitative systematic rating of healing environments in suburban London found that visual and auditory experiences were the most dominant landscape environment sensory response pathways, whereas smell, taste, and thermal environmental perception did not have a significant effect on healing health enhancement (51). Healing landscape evaluation studies have focused on safety and privacy, landscape configuration, ancillary functions, environmental comfort, rehabilitation facilities, and social support. In this study, based on the basic research above, a pilot study was conducted on 10 research samples to understand the specific needs and preferences of user groups in hospital landscapes and the rationality of indicator construction.

Synthesizing the research results and literature review, this study establishes a multilevel scale for healing environment needs, which contains 5 primary indicators and 18 secondary indicators (Table 1). Landscape demand aims to understand the differences in demand for visual, auditory, olfactory, tactile, and gustatory sensory stimuli among user groups. Functional demand aims to understand the difference in the user group's demand on landscape function configuration, including private space, security protection, and landscape walkway; experience demand aims to understand the difference in the user group's demand on social activities and interactive participation, including rehabilitation activities, gardening, and interactive experience; comfort demand aims to understand the difference in the user group's demand on natural ventilation, lighting, heat insulation, noise reduction, including shading, insulation, air volume regulation, and noise control. Maintenance needs aim to understand the differences in the needs of user groups for daily maintenance of the landscape environment, including resting seats, cleaning and maintenance, air purification, and medical escorts.

2.2.2 Questionnaire setting

The questionnaire is divided into two parts: the first part is the basic information of the user group, including gender, age, reason for visiting the hospital, frequency of visiting the hospital, visiting department, and length of stay; a total of six items; and the second part is the KANO questionnaire, corresponding to the secondary indicators set at a total of 36 positive and negative questions. Each question has a 5-level scale, and the options on the questionnaire scale correspond to the secondary needs individually (Supplementary Table S2).

The study samples were all located in the type IV seasonal zone, a region with long summers and no winters, high temperatures, and high humidity throughout the year, with mean temperatures above 10°C in January and approximately 25°C in July and a daily difference in mean annual temperatures of 5–12°C. Therefore, the daily and annual temperature differences in the area were small, the results of the study were less affected by the season, and the distribution of the study questionnaire was scheduled for spring. Previous studies have shown that temperature, noise, wind speed, and solar radiation variations have a direct effect on group perception and comfort evaluation, and special attention should be paid to the effects of extreme environmental factors (52–54). To reduce the physical impact of microclimate differences between different samples on the perception of the user group, we conducted a controlled variable study on the perceived microclimate related to comfort and measured the temperature, humidity, light, noise, wind speed, and air quality indicators of each research sample before distributing the questionnaires. The fluctuation of each indicator in the study sample was less than 30%, which enhanced the validity of the questionnaire by controlling for the fluctuation range of the physical environment.

The survey was conducted using a combination of electronic and paper questionnaires and was distributed from February to March 2023, with survey dates selected from Monday to Friday, from 9:00 to 12:00 and 14:00 to 18:00. The survey was conducted through random sampling in the field, and the target population was a user group located in the public landscape of a hospital. The sample size was 10 times the number of items on the KANO scale, and the total number of samples was at least 150. The number of questionnaires distributed to each hospital was 40–50. Therefore, the total number of questionnaires distributed in this study was 410, excluding some missing questionnaires and 22 invalid questionnaires. A total of 388 valid questionnaires were collected, and the statistical values are shown in Table 2.

Statistical analysis of the groups using the hospital pocket landscape indicated that 44.85% were male users and 55.15% were female users, with equal proportions and no obvious gender tendencies. The age range of the respondents showed a positive distribution, mainly concentrated in the 21–40 and 41–60 age groups, accounting for a total of 85.56%, reflecting that the frequency of use of the young and middle-aged groups was much higher than that of

TABLE 1 Hospital compact landscape environment healing needs index.

Firstly Requirements	Secondary requirements	Specific instructions	Number
Landscape requirements (A)	Visual perception	Planting of ornamental seasonal plants and composite landscaping	A1
	Auditory perception	Play music that helps to soothe the mood	A2
	Olfactory perception	Planting landscape plants with natural fragrance	A3
	Tactile perception	Installation of landscape vignettes that can be touched and felt	A4
	Taste perception	Provide a safe and hygienic source of drinking water	A5
Functional requirements (B)	Private space	Provide a hidden space that allows communication and relax	B1
	Security	Located in a safe and independent area, provides necessary protection measures	B2
	Landscape walkway	Provide walkable garden paths	B3
Experience requirements (C)	Rehabilitation activities	Provide rehabilitative equipment and devices	C1
	Gardening	Provide simple potted plants that can be watered or sown	C2
	Interactive experience	Provide the possibility of scientific research demonstrations and hand work.	C3
Comfort requirements (D)	Sunshade and heat insulation	Provide louvered roofs or wind and rain corridor	D1
	Air volume regulation	Provide wind compensation in the heat and wind shading in high winds	D2
	Noise control	Install natural barriers to reduce noise	D3
Maintenance requirements (E)	Resting seats	Add seats for rest and conversation	E1
	Cleaning and maintenance	Improve the maintenance of the hospital landscape. Keep the facilities clean and hygienic.	E2
	Purifying the air	Control of external emissions of medical gasses and dirt transport gasses	E3
	Medical escort	Medical accompaniment for patients with limited mobility and the older adult	E4

teenagers and older adult groups, and the demands of the latter two groups were easily ignored in the setting of the medical environment. In the group classification, outpatient and inpatient groups account for 47.94% of the total, indicating the extensive demand of patient personnel for hospital landscape environment settings, and the highest percentage of visiting escorts alone, reflecting the high dependence of this group on public environment places in the process of accompanying medical treatment, and the percentage of medical and nursing workers was only 20.62%. The proportion of those who stayed for less than 1 and 1–3 h was 19.59 and 62.89%, respectively, indicating that the medical environment mainly serves the short-stay group and is less likely to meet the needs of the group staying for a long time.

2.3 Statistical methodology

According to Noriaki Kano's theory and methodological tools, the KANO model categorical evaluation scale consists of forward and reverse questions with secondary indicators and generates a five-level quality categorical assessment matrix table consisting of satisfactory, deserved, neutral, tolerable, and unsatisfactory (34, 39–42). The KANO model divides the demand quality attributes into five categories, including attractive quality (A), expected quality (O), must-be quality (M), indifferent quality (I), reversal quality (R), and questionable quality (Q), a total of six items (Supplementary Table S3). When the hospital landscape provides sufficient attractive quality, the satisfaction of the user group increases, and when it is lacking, there is no effect, which is an unexpected surprise: when the expected quality is sufficient, the satisfaction of the user group increases, and vice versa; no increase in satisfaction of the user group when the expected quality is sufficient, and vice versa, a decrease, being an unexpected need; indifferent quality has no significant effect on the satisfaction of the user group regardless of whether they are sufficient. When the reversal quality is sufficient, it will cause dissatisfaction in the user group; otherwise, it will increase, and it belongs to the content to be controlled. Questionable quality is a problem that confuses respondents, and the proportion of this demand should be controlled.

Quantitatively classify and analyze the needs of user groups. For a certain need (i), the proportion of the demand for a particular group is A_i, O_i, M_i, I_i and the percentage of the demand is B_i and W_i. The formula used is as follows:

$$B_i = \frac{(O_i + A_i)}{(A_i + O_i + M_i + I_i)} \quad \bar{B} = \sum_{i=1}^{m} B_i$$

$$W_i = \frac{(O_i + M_i)}{(A_i + O_i + M_i + I_i)} \quad \bar{W} = \sum_{i=1}^{m} W_i$$

where B_i is the rate of satisfaction improvement for the group of users meeting this demand, $\bar{B}$ is the mean value of each satisfaction, W_i is the rate of decrease in satisfaction for the group of users who do not satisfy the demand, and $\bar{W}$ is the average value of dissatisfaction. Based on the better–worse coefficient values as the horizontal and vertical axes, the demand types can be classified into four quadrants (Supplementary Figure S1). The first is the quadrant X, where W_i are greater than their mean values $\bar{B}$ and $\bar{W}$, making it the "expectation demand" quadrant, which is the landscape environment that should

TABLE 2 Basic information statistics of the research sample.

Respondent information statistics				Site microclimate statistics				
Projects	Category	Quantity	Proportion	Microclimate measurements	Average value	MIN	MAX	SD
Gender	Male	184	47.42%	Noise (dB)	56.2	48.2	66.2	4.61
	Female	204	52.57%	Lightness (LUX)	3,056	2,532	4,217	720
Age	≤20 years old	12	3.09%	Wind speed (M/s)	1.23	0.13	2.54	0.64
	21–40 years old	170	43.81%	Humidity (%)	49.0	31.9	64.3	14.5
	41–60 years old	162	41.75%	Body temperature (°C)	21.3	18.1	25.4	2.8
	≥60 years old	44	11.34%	Tiling temperature (°C)	19.7	11.4	29.7	7.6
Group type	Outpatient	94	24.23%	Vegetation temperature (°C)	18.4	10.2	27.3	5.3
	Inpatient treatment	92	23.71%	TVOC (mg/m^3)	0.16	0.006	0.19	0.021
	Visiting companion	122	31.44%	HCHO (mg/m^3)	0.007	0.002	0.012	0.004
	Medical worker	80	20.62%	PM2.5 (ug/m^3)	27	20	32	4
Length of stay	≤1 h	76	19.59%	CO (ppm)	1	0	3	1
	1–3 h	244	62.89%	CO2 (ppm)	508	405	570	81
	3–6 h	32	8.25%	Sky view factor (%)	55.1	37.6	73.2	14.2
	≥6:0 h	36	9.28%	Overall quality evaluation	Excellent	Good	Excellent	-

be continuously maintained to set items. In the second quadrant, B_i is less than $\overline{B}$ and W_i is greater than $\overline{W}$, which is a "necessary demand" quadrant, for the landscape environment must exist in the content. In the third quadrant, B_i and W_i are less than the average value $\overline{B}$ and $\overline{W}$, making it the "irrelevant demand" quadrant, which belongs to the landscape environment that cannot consider the setting content. In the fourth quadrant, B_i is greater than $\overline{B}$ and W_i is less than $\overline{W}$, which is the "charm demand" quadrant, which belongs to the landscape environment in the selective optimization of the configuration of the content. Through the importance of each quadrant demand, it is known that the importance of demand is "necessary demand > expectation demand > charm demand > irrelevant demand."

3 Results

The reliability and validity of the questionnaire were tested using the SPSS software. The magnitudes of several test values for the questionnaire are listed in Table 3. The Cronbach's test values of the overall questionnaire, positive, and negative questions are between 0.8 and 0.9, and the reliability of the questionnaire is at a good level. The Kaiser–Meyer–Olkin measure values of the overall questionnaire for positive and negative questions are between 0.7 and 0.8, and the validity is at a reasonable level. Bartlett's sphere test has a significance probability of 0.000, which is less than 0.01, with a reasonable correlation.

3.1 Demand attribute identification

The B–W attribute classification table was obtained using the KANO model 5 × 5 quality classification evaluation matrix (Table 4), in which the questionable demand (Q) accounted for less than 5% of the total, in line with the attribute classification requirements. Among them, the must-be needs (M) are five items in total, including B1 privacy space, B2, security protection, D1 shelter and heat insulation, D3 noise control, and E1 resting seats, which are the environmental configuration that the hospital pocket landscape must have, otherwise it directly affects the satisfaction of the user group; the expected needs (E) are five items in total, including A1 visual perception, A2 landscape walkway, C1 rehabilitation activities, E2 cleaning and maintenance, E3, purified air, and E4 medical escort, which the user group thinks should be available; attractive needs (A) are five in total, including A3 smell perception, A5 taste perception, B3 landscape walkway, C3 gardening planting, and D2 wind control; indifferent needs (I) are three in total, including A2 auditory perception, A4 tactile perception, and C3 interactive experience, for which the user group has no significant demand for such functions.

3.2 Sensitivity analysis

The contents of Table 4 are divided into four quadrants: the mean value of the better coefficient $\overline{B}$ was 0.34, and the average value of the worse coefficient $\overline{W}$ was 0.30. The primary evaluation of demand satisfaction is achieved through the four-quadrant diagrams, but it is not possible to realize the demand priority in each demand quadrant, combined with Yang's research on perceived importance, sensitivity (R_i), and weighting ratio (F_i). The quantitative index of each demand was calculated using Yang's perception of importance, and the priority of each demand in the same quadrant was compared horizontally using the score value.

$$R_i = \sqrt{B_i^2 + W_i^2} \quad (1)$$

$$F_i = \max\left[\frac{B_i}{\sum_{i=1}^{m} B_i} \quad \frac{W_i}{\sum_{i=1}^{m} W_i}\right] \tag{2}$$

iis a particular demand and R_i is the sensitivity of the demand (the larger the value, the clearer the sensitivity perception of the user group). F_i is the relative weight ratio of the demand, which describes the relative importance of each demand of the user group.

According to the quadrant coordinate values (Figure 2), the highest sensitivity in the M-q quadrant is private space (B1), indicating that the lack of relatively independent environmental places in the public landscape to reduce outside interference will significantly reduce the satisfaction of the user group; the highest sensitivity in the E-q quadrant is the medical escort (E4), indicating the importance of having medical personnel present in the public landscape to accompany, which shows a strong correlation with the satisfaction of the user group. The highest sensitivity in the A-q quadrant is gardening (C2), indicating that the provision of certain watering and cultivation experiences has a positive effect on the psychological state of the user group and can be considered for medical landscape systems. The highest sensitivity in quadrants I-q is for auditory perception (A4), indicating that the presence of sound in the landscape environment tends to have a direct effect on user groups, but the demand is not significant.

According to the quadrant classification results (Table 5), we can know that the priority ranking of each attribute requirement is "M-q > E-q > A-q > I-q," the initial ranking is conducted, and the secondary ranking of each requirement category is achieved through relative weighting. That is, the final result is that the must-be requirements (E1 > B1 > D1 > B2 > D3) are better than the expected requirements (E4 > E3 > E2 > A1 > C1), attractive requirements (D2 > C2 > A5 > B3 > A3), and indifferent requirements (A4 > C3 > A2).

3.3 Importance analysis

The data for each demand sub-item under primary demand R_i were developed (Table 6). According to the ranking of the mean value of the primary needs, we can see that maintenance management (67.06%) > functional planning (47.51%) > comfort enhancement (46.16%) > experience participation (35.77%) > landscape healing (34.58%), reflecting that the importance of maintenance management is much higher than other primary needs in the hospital healing landscape. Among these, the importance of medical escorts (E4) is the most significant, reflecting that the user group needs a certain amount

TABLE 3 Questionnaire validity and reliability tests.

Content	Number of items	Cronbach's alpha	KMO Metric	Bartlett's sphericity test
Positive problem (n = 388)	18	0.814	0.753	0.000
Negative problem (n = 388)	18	0.849	0.819	0.000
Overall problem (n = 388)	36	0.858	0.705	0.000

TABLE 4 Summary of results for B–W attributes of the KANO model (N = 388).

Demand	A (%)	O (%)	M (%)	I (%)	R (%)	Q (%)	B_i (%)	W_i (%)	B–W
A1	21.65	17.01	14.43	45.36	0.52	1.03	39.27	31.94	E
A2	9.28	4.12	1.03	80.93	3.61	1.03	14.05	5.41	I
A3	22.68	10.31	1.55	53.61	11.34	0.52	37.43	13.45	A
A4	8.25	8.76	5.67	65.46	10.82	1.03	19.30	16.37	I
A5	24.74	9.28	6.70	48.45	10.31	0.52	38.15	17.92	A
B1	13.92	18.04	21.65	41.75	4.12	0.52	33.51	41.62	M
B2	21.13	10.31	27.84	38.66	2.06	0.00	32.11	38.95	M
B3	27.32	10.31	1.80	57.47	1.03	2.06	38.83	12.50	A
C1	15.46	20.62	10.31	52.58	1.03	0.00	36.46	31.25	E
C2	18.04	18.04	5.15	57.73	1.03	0.00	36.46	23.44	A
C3	7.73	5.15	1.03	75.77	9.79	0.52	14.37	6.90	I
D1	10.31	20.10	19.59	47.42	2.06	0.52	31.22	40.74	M
D2	23.20	15.46	5.15	55.15	1.03	0.00	39.06	20.83	A
D3	10.82	12.89	19.07	50.00	6.70	0.52	25.56	34.44	M
E1	10.31	16.49	24.7	44.33	3.09	1.03	27.96	43.01	M
E2	14.95	29.38	10.82	42.78	2.06	0.00	45.26	41.05	E
E3	9.79	35.57	13.92	37.11	2.06	1.55	47.06	51.34	E
E4	11.34	47.94	13.40	26.29	0.52	0.52	59.90	61.98	E

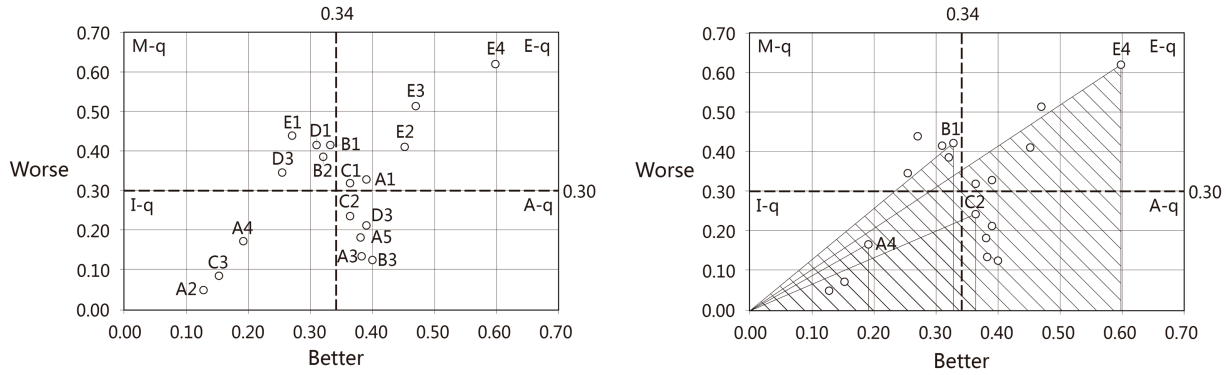

FIGURE 2
Sensitivity analysis.

TABLE 5 Demand sensitivity ranking.

B–W	Number	R_i	F_i	Order	B–W	Number	R_i	F_i	Order
M-q	E1	0.5130	0.1850	1	E-q	C1	0.4802	0.1329	10
	B1	0.5344	0.1732	2	A-q	D2	0.4427	0.1526	11
	D1	0.5133	0.1660	3		C2	0.4334	0.1329	12
	B2	0.5047	0.1517	4		A5	0.4215	0.1455	13
	D3	0.4289	0.1186	5		B3	0.4079	0.1508	14
E-q	E4	0.8619	0.3841	6		A3	0.3977	0.1401	15
	E3	0.6964	0.2635	7	I-q	A4	0.2531	0.0372	16
	E2	0.6111	0.2049	8		C3	0.1594	0.0206	17
	A1	0.5062	0.1542	9		A2	0.1506	0.0198	18

of escort support when they go out during the rehabilitation process. The importance of functional planning (47.51%) and comfort enhancement (46.16%) are similar, and the standard deviation of the importance of each secondary subparagraph is small and fluctuates little, indicating that the user groups have a higher demand for various functional settings and comfort in the medical landscape. The importance of the former private space (B1) is higher, indicating that the user groups also need relatively independent space in the public landscape environment. The latter has a higher importance for shading and heat insulation (D1), indicating that user groups in the public environment have a significantly higher perception of light and heat than of both ventilation and noise. The mean values of landscape healing (34.58%) and experience participation (35.77%) were close to each other and significantly lower than those of the first three, and the standard deviations of the secondary subscripts are larger and fluctuate greatly, indicating that there are some differences in the specific needs of user groups. The former has a higher importance of visual perception (A1), reflecting that the effect of visual stimulation is better than the rest of sensory perception; the latter has a high importance of rehabilitation activities (C1), indicating that the user groups have a higher perception of the medical healing landscape in the public environment than the other two. The higher importance of the latter rehabilitation activity (C1) indicates that user groups have greater demand for rehabilitation facilities to be configured in the public environment of a medical healing landscape.

3.4 Group variability analysis

The statistical data were divided into three research groups: age, type, and length of stay, and the sensitivity of each secondary index in the top three groups was ranked to analyze their demand preferences (Table 7). The sensitivity rankings of functional planning, experience participation, and comfort enhancement were the same in each group, with the most significant demands for private space B1, rehabilitation activity C1, and sunshade and heat insulation D1.

Among the ≤20 years and ≥ 60 years age groups, the sensitivity of auditory perception is high, while the sensitivity of visual perception of 21–40 years old and 41–60 years old groups is better than other sensory perception. In terms of functional planning, the ≤20 years old group values the possibility of touring the garden in healing landscape design, while the rest of the age groups value the creation of private space. Regarding management and maintenance, the 21–40, 41–60, and ≥ 60-year-old groups think that purifying air should be an important demand item after medical care accompaniment. From the age group data and on-site interviews, it can be seen that the sensory organs of the adolescent group are still developing; they are full of curiosity about the outside world, and they are looking forward to exploring fresh and unfamiliar surroundings through their limbs. Young and middle-aged groups rely more on vision to receive external information and form feedback, whereas the older adult group is relatively poor in physical condition, is at a disadvantage in functional

TABLE 6 Demand importance ranking.

Firstly requirements	Mean (%)	Max (%)	Min (%)	SD (%)	Secondary subordination
Landscape requirements A	34.58	15.06	50.62	12.72	A1 > A5 > A3 > A4 > A2
Functional requirement B	47.51	40.79	53.16	5.11	B1 > B2 > B3
Experience demand C	35.77	15.94	48.02	14.15	C1 > C2 > C3
Comfort demand D	46.16	42.89	51.33	3.69	D1 > D2 > D3
Maintenance requirements E	67.06	51.30	86.19	12.81	E4 > E3 > E2 > E1
Primary demand mean ranking: E > B > D > C > A					

TABLE 7 Ranking of differential needs of the group.

Group	Category	Landscape healing	Functional planning	Experience participation	Enhanced comfort	Management maintenance
Age	≤20 years old	A2 > A2 > A4	B3 > B1 > B2	C1 > C2 > C3	D1 > D2 > D3	E4 > E1 > E2
	21–40 years old	A1 > A3 > A3	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E4 > E3 > E1
	41–60 years old	A1 > A3 > A4	B1 > B3 > B2	C1 > C2 > C3	D1 > D2 > D3	E4 > E3 > E1
	≥60 years old	A2 > A1 > A4	B1 > B3 > B2	C1 > C2 > C3	D1 > D2 > D3	E4 > E3 > E1
Group Type	Outpatient	A1 > A4 > A5	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E4 > E1 > E3
	Hospitalization	A1 > A5 > A3	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E4 > E1 > E3
	visitation	A1 > A2 > A5	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E4 > E2 > E3
	Medical staff	A1 > A2 > A3	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E2 > E3 > E1
Length of stay	≤1 h	A1 > A2 > A3	B1 > B2 > B3	C1 > C2 > C3	D1 > D2 > D3	E1 > E2 > E4
	1–3 h	A1 > A2 > A5	B1 > B2 > B3	C1 > C2 > C3	D2 > D3 > D1	E1 > E2 > E4
	3–6 h	A1 > A3 > A5	B1 > B3 > B2	C1 > C2 > C3	D2 > D3 > D1	E1 > E4 > E3
	≥6 h	A1 > A5 > A2	B1 > B3 > B2	C1 > C2 > C3	D2 > D3 > D1	E4 > E1 > E3

and mental recovery, often with stage mental disorders, and shows a higher demand for external healthcare accompaniment.

Among the group types, the difference in needs between the outpatient and inpatient patient groups and the visiting and medical care groups focused on auditory perception, the latter being higher than the former, with the former showing some need for tactile perception, A4, and taste perception. In functional planning, the rankings of experience participation and comfort requirements are the same. In terms of management and maintenance, the outpatient and inpatient groups focused on the adequacy of resting and seating facilities, while the visiting and medical care groups examined whether the degree of tidiness was guaranteed. From the group-type statistics and on-site interviews, it can be seen that the outpatient and inpatient groups often rely on public seating and open space to relieve the fatigue of the recovery process because their bodies are in a state of recovery or discomfort, and their poor mental state also reduces their auditory sensitivity. Visiting and healthcare groups believe that a clean hospital environment is not only conducive to the recovery of the patients but also a hygienic safeguard for the work of the visiting doctors.

In the length of stay group, each group was most sensitive to visual perception, and the main difference was that as the length of stay increased, the sensitivity to the demand for smell and taste perception gradually increased. In terms of management and maintenance indicators, an increase in resting seats and medical escorts was also positively correlated with the length of stay. From the stay time statistics and on-site interviews, it can be seen that the crowd in the hospital public environment with an increase in stay time, anxiety, and boredom will gradually accumulate and need to adjust to bad mood through travel or activities. A long stay increases the knowledge of the crowd about an unfamiliar environment and reduces their precautions regarding the surrounding environment. In addition, there is a need for more resting seats in courtyards to ease the physical exertion of long stays.

4 Discussion

The object of this study is austere general hospitals, and no category study has been conducted on special specialist hospitals and hospices; however, the medical landscape needs are discussed in terms of universal design for different groups of people of all ages and are therefore applicable in the design of healing environments. By introducing the KANO theory, this study establishes four quadrant models of needs, and this technical route is efficient, targeted, and easy to implement. The main differences between research on hospital healing environments and traditional multifactor mathematical statistics methods are as follows: 1. Taking the needs of the user group as the fundamental starting point, it ranks demand priorities quickly, whereas traditional research methods such as multiple logistic regressions, principal component analysis, and AHP are used to conduct data correlation analysis and determine its potential

mathematical and physical laws from qualitative to quantitative levels. 2. With the ultimate goal of improving the satisfaction of the user group, this method can assist management decision-makers and provide data support to maximize the rational utilization of resources when facing a balance of limited resource allocation. 3. In terms of implementation difficulty, the method has a clear technical process, is friendly to researchers in non-statistical disciplines, and the research content is demand-driven, allowing for iterative research in response to the needs of specific projects.

This study has certain limitations. First, the evaluation index system in this study was based on the statistics of the existing healing landscape research literature, and there is no unified consensus on the evaluation system of the hospital healing landscape in the academic field. Therefore, this study failed to achieve a comprehensive, objective, and systematic index construction process, and further optimization is required. Second, in the research stage, the KANO questionnaire needs to set positive and negative questions; if there are many indicators of landscape healing needs, it will directly lead to multiple questions, and the final completion rate of the questionnaire will affect the validity of the data. The KANO model only provides a type of demand study and lacks judgment on the difficulty of implementing measures to meet demand, which reduces the operability of optimizing the hospital healing landscape environment. Furthermore, due to the limitation of controlling the influencing factors and research efforts, the scope of this study focused on the IV hot summer and cold winter areas in the "China Building Climate Zoning," which failed to comprehensively consider the healing needs of the patients under the influence of different climates and can be performed as a series of research studies.

This study only investigated the healing needs of the hospital landscape environment. The evaluation index system could be optimized by introducing AHP with a team of experts, user groups, and administrative personnel to assist in the evaluation and improve the research questionnaire. Simultaneously, to improve the feasibility of the study, future research can form a KANO-QFD composite model through the quality function configuration and build a quantitative method to satisfy the difficulty of a certain demand.

5 Conclusion

In this study, based on the KANO model, a demand questionnaire for the hospital healing landscape environment was developed to analyze positive and negative demand deviations. Four major quality attributes–must-be quality, expected quality, attractive quality, and indifferent quality–were classified by the better–worse coefficient, and sensitivity and relative weight were introduced to derive the demand ranking of each secondary index. The validity and reliability of each questionnaire were statistically significant. The main findings of this study are as follows:

(1) The ranking of the mean values of sensitivity to the needs of the user groups (Table 6) showed maintenance management (67.06%) > functional planning (47.51%) > comfort enhancement (46.16%) > experience participation (35.77%) > landscape healing (34.58%). Given the limited resources of the hospital landscape, it is necessary to strengthen maintenance management efforts, maximize functional planning and comfort facilities, and appropriately reduce the items of sensory healing and experimental participation in healing needs.

(2) For settings of hospital landscape environment healing, the healing perception level gives priority to setting visual perception landscape elements, followed by olfactory perception, with no obvious demand for preference for auditory perception and tactile perception landscape elements. The functional planning level needs to focus on the balance between the supply and demand of private and open spaces and provide a relatively independent and safe space for the user group. For the hospital landscape with site conditions, consideration can be given to setting up a landscape tour space. At the level of comfort enhancement, special attention should be paid to the configuration of shading and heat insulation facilities, followed by the control of the acoustic environment, and then wind environment control. At the level of maintenance and management, the medical and nursing staff can greatly enhance the satisfaction of all users, while the environment should be kept as neat and clean as possible to reduce the spread of medical odors.

(3) For the study of group variability, it can be seen that the needs of different age groups for the healing landscape have particular preferences; juvenile and older adult groups have some commonalities and contradictions, while the needs of young and middle-aged groups are highly overlapping, and the incremental increase in age shows an increase in dependence on medical and nursing accompaniments. In terms of group type, the outpatient and inpatient groups paid more attention to the visual and tactile environmental needs than the visiting and medical groups. In addition, with the increase in time spent in public environments, there is a significant increase in the need to experience the diversity of the environment, resting space, healthcare accompaniment, and olfactory and gustatory senses, and a decrease in the sensitivity of safety and security.

The results of this study can lay the background for the development of healing landscapes in high-density urban spaces, as well as guide the sustainable development of landscapes in hospital ecosystems at a more refined spatial and temporal scale. Moreover, it provides sustainable strategies for progressively tightening the medical landscape. Furthermore, our approach can be extended to similar social ecosystems in small-scale landscape development planning.

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 authors.

Author contributions

HG: investigation, data collection, formal analysis, visualization, writing–original draft, and project administration. WZ: investigation, data collection, formal analysis, visualization, and writing–original draft. WL: conceptualization, funding acquisition, methodology,

supervision, and project administration. LY: supervision, methodology, and writing–review and editing. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

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University indigenous students' perspectives on climate change and survival of indigenous peoples in Brazil: a concept mapping study

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Introduction: This study aimed to identify what indigenous university students in Brazil perceived to be important and feasible actions to protect the survival of indigenous peoples from climate change-related impacts.

Methods: Concept mapping, which is a participatory mixed methodology, was conducted virtually with 20 indigenous students at two universities in Brazil. A focus prompt was developed from consultations with indigenous stakeholders and read "*To protect the survival of the Indigenous Peoples from climate change, it is necessary to…*". Students brainstormed 46 statements, which they then sorted into clusters based on conceptual similarity. They rated each statement for importance and feasibility. Quantitative multivariate analyses of clusters and ratings were conducted to produce multiple visual maps of perceived actionable priorities. These analyses used the Group Wisdom TM software.

Results: Students agreed on 8 clusters that reflect the factors that influence the survival of indigenous peoples-preservation of lands 0.16 (SD 0.13), protection of demarcated lands 0.31 (SD 0.10), indigenous health and wellbeing 0.35 (SD 0.14), ancestral customs 0.46 (SD 0.04), global and national actions 0.61 (SD 0.13), indigenous rights 0.64 (SD 0.23), collective living 0.71 (SD 0.21), and respect 0.75 (SD 0.14).

Discussion: The most actionable priorities are related to the respect for their lands and customs, educational initiatives in schools about the importance of indigenous peoples to society, guarantees for basic health rights, and culturally appropriate provision of care, with specific mention of mental healthcare. The findings aligned closely with the concept of indigenous self-determination, which is rooted in autonomy and respect for cultural diversity, and the right to make decisions that impact their lives, land, and resources.

KEYWORDS

indigenous, climate change, land loss, survival, health, concept mapping, community based participatory research

1. Introduction

Climate change has had a significant impact on indigenous people in Brazil. Brazil is home to ∼900,000 indigenous peoples belonging to about 305 ethnic groups (1). Rising temperatures and changing rainfall patterns have led to crop failures and food insecurity, making it increasingly difficult for communities to maintain traditional livelihoods such as hunting and fishing (2–4). As with global indigenous populations, connection to nature is central to their daily practices and beliefs. The environment is closely tied to the identity of indigenous communities, and this connection is reflected in their traditional practices, customs, and beliefs (5). For many indigenous communities, the land is not just a physical place but also a source of identity, history, and spiritual wellbeing.

Reciprocity is an essential principle in indigenous cultures; it refers to mutual energy exchange between humans and the natural world. This manifests in the form of traditional practices such as ritual offerings or ceremonies that are performed to maintain balance between humans and the environment. The principle is rooted in the belief that all living beings, including humans, are interconnected and interdependent (5, 6). A lack of reciprocity impacts the ability to engage in traditional practices, disrupts cultural continuity, and widens indigenous health disparities (7). The most pressing challenge relates to deforestation, which also impacts the rainforests' crucial role in stabilizing the global climate and indigenous survival. The report released by the Intergovernmental Panel on Climate Change (IPCC), titled "Climate Change 2021: The Physical Science Basis", highlighted that man-made changes are irrefutable and will worsen if we do not take practical actions to change the narrative of the climatic, environmental, and societal crises (8).

International organizations have increasingly recognized indigenous people's rights to health and wellbeing (9–11). The United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) provides an international framework to ensure indigenous populations' survival, dignity, and wellbeing worldwide (11). Many of the sustainable development goals (SDGs) are relevant to the welfare of indigenous people, particularly those that relate to addressing health and socio-economic inequalities. Reference is made to indigenous people (though only 6 times) in the SDGs, in the targets under Goal 2 on Zero Hunger and Goal 4 on education (12). In 2017, the World Health Organization published "Policy on Ethnicity and Health" (13), which highlighted strengthening the institutional and community capacity to generate evidence for policy-making to address the inequalities in health experienced by indigenous peoples. The report by the Pan American Health Organization (PAHO) "Health Plan for Indigenous Youth" identified several priority areas, including access to intercultural health services, traditional medicines, mental health, disabilities, and violence (14).

Young indigenous peoples are increasingly contributing to global discussion forums. They had a strong presence in the 27th Conference of the Parties of the United Nations Framework Convention on Climate Change. Despite this historic step change in participation, protecting indigenous peoples in the Global Goal on Adaptation was weak (15). Exclusion in decision-making promotes feelings of powerlessness, which links to a disproportionate burden of poor health (15, 16). Findings from the Xunati Uti study in Mato Grosso do Sul, Brazil showed that indigenous adolescents perceived their health and happiness to be influenced by their ecosystems, family life, friendships, nature, and belonging to a strong community (17). In a national survey in Brazil on violence against youths (2011–2017), only 1% of the sample was indigenous (n = 3,467), but the findings showed a higher likelihood of physical (71.8 vs. 63.3%) and sexual (29.8 vs. 21.3%) violence compared with White Brazilian youths (18). There are also concerns over high rates of substance use and suicides and that deforestation, climate-related disasters, and disproportionate impacts of COVID-19 have exacerbated mental health problems, however, mental healthcare is limited (19, 20). Expenditure on mental health in Latin America is generally inadequate (∼2% of total public expenditure on health), particularly for community care, as ∼61% is disbursed to inpatient psychiatric care (21).

The current study used a mixed-methods approach of concept mapping (CM) to identify what indigenous university students perceived to be important and feasible actions to protect the survival of indigenous peoples from climate change-related impacts (22). Concept mapping prioritizes stakeholder engagement at every stage of the research process, aligning well with principles of indigenous self-determination and gearing the focus of the research toward potentially translational learning for policymakers, implementors, and communities (23).

2. Methods

2.1. Ethics and recruitment

Ethical approval for this study was obtained from the National Research Ethics Commission (CONEP), protocol CAAE 36372820.0.0000.8027 from May 25th, 2021. All students signed an agreement form.

One researcher at UEMS (Universidade Estadual de Mato Grosso do Sul) and one researcher at UFRGS (Universidade Federal de Rio Grande do Sul) advertised the study among indigenous students. Concept mapping activities took place between August and September 2021.

This was a convenience sample and students attended the university of the authors (AJG and IMAVD). Each year, four indigenous youths are offered a scholarship to undertake undergraduate courses (for example, medicine, nursing, and psychology). A total of 20 indigenous university students were invited to participate in the study, and all agreed to take part.

Abbreviations: LAC, Latin America and the Caribbean; UNDRIP, United Nations Declaration on the Rights of Indigenous Peoples; ICHW, Indigenous Community Health Workers; FUNAI, The National Indian Foundation; IPCC, Intergovernmental panel on climate change.

2.2. Study design

2.2.1. Concept mapping

Four meetings were conducted virtually through Google Meet, each lasting between 30 min and 2 h. Participatory CM is a structured process that generates statements from the discourse of students, which are later sorted and rated for importance and feasibility (24). The key steps include (1) brainstorming in response to a focus prompt, (2) sorting and rating, and (3) map interpretation sessions. All steps were conducted in a virtual environment. Each session was facilitated by researchers.

2.2.2. Brainstorming

The first meeting was held to explain the objective of the research and obtain participant consent. Following consent, students completed an online demographic questionnaire. The brainstorming activity was guided by the focus prompt:

> *"To protect the survival of the Indigenous Peoples from climate change it is necessary to…"*

Each student was asked to write their statements on paper during the brainstorming session and send statements via email to the facilitating researcher. In total, 104 statements were generated. Researchers removed repeated statements and, in discussion with the students, amended some statements for clarity. The final list included 46 statements.

2.2.3. Sorting and rating

Each student was invited to organize the 46 statements into clusters based on what they perceived to be conceptually similar using an online Google Form. Students were then asked to rate each statement on the Google Form according to their perception of importance and feasibility, using a 5-point Likert scale. The questions read "*How important are each of the following statements regarding climate change and the adaptation of Indigenous People to it?*" and *"How feasible is it to implement each of the following statements into practice?*" The 5-point rating scales were: 1 = Relatively unimportant, 2 = Somewhat important, 3 = Moderately important, 4 = Very important, 5 = Extremely important; and for the feasibility of achieving a positive change: 1 = Not at all feasible, 2 = Somewhat feasible, 3 = Moderately feasible, 4 = Very feasible, 5 = Extremely feasible.

A third session was held to discuss the multidimensional maps with students to agree on appropriate clusters.

2.2.4. Feedback session with students

A fourth session was held to discuss the results with students and ensure their validation of the results. The students were encouraged to make any changes they felt necessary to improve the representation of the results. They discussed the 8-cluster map and agreed it was the best representation of the key ideas.

2.3. Data analysis

Quantitative multivariate analyses of clusters and ratings were conducted to produce multiple visual maps of perceived actionable priorities. These analyses used the Group Wisdom TM software (22). All data collected through emails and Google forms were entered manually by two researchers and double-checked. First, a matrix of similarities was generated to check the statements and the labels given to each group of statements. Second, multidimensional scaling (MDS) analysis was then used to create a two-dimensional "point map". Each statement was represented as a numbered point, with points closest together more conceptually similar. The stress value of the point map is a measure of how well the MDS solution maps the original data, indicating a good fit. Stress values range from 0 to 1, with lower values indicating better fit. The acceptable range for stress values is 0.205–0.365 (25). Finally, hierarchical cluster analysis was used to delineate clusters of statements (points) that were conceptually similar to create cluster maps based on the positioning of the statements on the point map. Cluster labels were determined by the indigenous students. Clusters with low bridging values (BV) indicate high agreement among students in the clustering of statements. Go-zone graphs showed the most actionable (high importance and high feasibility) and least actionable (low importance and low feasibility) statements (24).

3. Results

3.1. Profile of participating students

Twenty indigenous university students from Mato Grosso do Sul and Rio Grande do Sul states participated in all steps; 60% were

TABLE 1 Demographic characteristics of participating students.

Age	Mean	*N*	%
	25.25 y (SD4.63)		
Gender	Male	8	40
	Female	12	60
Marital status	Not married	18	90
	Married	2	10
Ethnicity	Kaingang	10	50
	Pitaguary	1	5
	Terena	3	15
	Atikum	4	20
	Arapium	1	5
	Tabajara	1	5
Income support	Scholarship	13	65
	Parents help	3	15
	None	4	20
Urban–rural residence before university	Urban	8	40
	Rural	12	60

women ($n = 12$) and 90% were not married ($n = 18$). Half of the stakeholders were of Kaingang ethnicity ($n = 10$) and received a university stipend ($n = 13$), and 60% considered themselves as rural indigenous ($n = 12$) (from a rural area).

Participant sociodemographic characteristics are presented in Table 1.

3.2. Cluster map

Statements and bridging values for each statement and cluster are presented in Table 2. The statements were assigned to 8 clusters: preservation of lands 0.16 (SD 0.13), respect 0.75 (SD 0.14), collective living 0.71 (SD 0.21), indigenous rights 0.64 (SD 0.23), protection of demarcated lands 0.31 (SD 0.10), ancestral customs 0.46 (SD 0.04), global and national actions 0.61 (SD 0.13), and indigenous health and wellbeing 0.35 (SD 0.14). Figure 1 shows the 8-cluster map. The layers of each cluster reflect the degree of agreement across students in the clustering of statements, with a few layers representing higher correspondence in clustering across the students. The highest agreement among students in the clustering of statements was for the following clusters: **preservation of lands; protection of demarcated lands; ancestral customs; and indigenous health and wellbeing**.

3.2.1. Preservation of lands, protection of demarcated lands, ancestral customs, and indigenous health and wellbeing

The cluster **Preservation of lands** had a BV of 0.16 (SD 0.13) and 10 statements with a mean rating for importance of 4.6 (SD 0.68) and feasibility of 3.77 (SD 1.07). The students' statements highlighted the urgency for nature preservation, stopping deforestation and river pollution, and recovering biodiversity. The cluster **Protection of Demarcated Lands** had a BV of 0.31 (SD 0.10) and 4 statements with a mean rating for importance of 4.58 (SD 0.71) and feasibility of 3.86 (SD 1.23). The students' statements focused on the enforcement of the law to disallow the use of their lands for profit. Although **Ancestral customs** had a BV of 0.46, (SD 0.04); mean ratings for importance 4.55 (SD 0.71) and feasibility 3.78 (SD 1.14)] formed a separate cluster, the emphasis was similar. The 4 statements emphasized the urgency of implementing laws for land protection. The cluster **indigenous health and wellbeing** had a BV of 0.35 (SD 0.14) and seven statements with a mean rating for importance of 4.42 (SD 0.71) and feasibility of 3.98 (SD 1.09). The statements focused on the need for basic sanitation, clean potable water, and safe disposal of human waste in their villages, educational initiatives in schools about indigenous peoples and their importance in society, and access to healthcare (particularly mental healthcare).

3.2.2. Global and national actions, indigenous rights, collective living, and respect

The high BVs for these clusters reflected variations in the clustering of statements across students, but the ratings of the statements reflected moderate importance and feasibility. **Global and national actions** [BV 0.61 (SD 0.13); mean ratings for importance 4.45 (0.71) and feasibility 3.63 (1.24)] highlighted the need for a review of global guidelines related to the environment, taxation to prevent countries implementing actions that have negative environmental impacts, and for preventing illegal activity (e.g., mining) which degrades the land and pollutes the water. **Indigenous rights** [BV of 0.64 (0.23); importance 4.53 (0.67) and feasibility 3.87 (1.17)] highlighted the need for systems to ensure the demarcation of their lands which they depend on for their livelihoods. **Collective living** [BV 0.71 (0.21); importance 4.15 (0.94) and feasibility 3.53 (1.24)] highlighted the loss of natural habitat and land scarcity. **Respect** [BV 0.75 (0.14); importance 4.36 (0.79) and feasibility 3.75 (1.09)] highlighted respect for indigenous peoples as stewards of the earth and for their cultural habits. The statements reflect overlapping meanings which explains the lack of close correspondence across the students in clustering.

3.3. Go zone map

Go map zone is presented in Figure 2. The Go Zone map gives a visual representation of actionable priorities generated from the statements. The upper right-hand quadrant represents the statements that were rated most important and feasible to implement. The most highly rated statements on both importance and feasibility (mean ratings of ≥ 4) are related to the demarcation of and respect for their lands, educational initiatives in schools about indigenous peoples, and having a guarantee for basic health rights that considers their culture. Statements that were reported as least important and feasible are those in the lower left-hand quadrant. Examples of these statements included a "review of global guidelines related to the environment" and "live collectively, knowing that one depends on the other and that everyone depends on nature".

4. Discussion

4.1. Principal findings

University students identified eight clusters that reflected the key factors that influence the survival of indigenous peoples in the context of climate change—preservation of lands, protection of demarcated lands, indigenous health and wellbeing, ancestral customs, global and national actions, indigenous rights, collective living, and respect. The most actionable priorities are related to the respect for their lands and customs, educational initiatives in schools about the importance of indigenous peoples to society, guarantees for basic health rights, and culturally appropriate provision of care. These findings align closely with the concept of indigenous self-determination, which is rooted in autonomy and respect for cultural diversity, and the inherent right to make decisions that impact their lives, land, and resources. Self-determination is critical to upholding human rights, social justice, and reconciliation, fostering partnerships based on mutual respect, and enabling indigenous peoples to contribute to local, national, and global development agendas while safeguarding their rights, lands, and identities (26).

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TABLE 2 Clusters with their statements: bridging values and importance and feasibility ratings (standard deviation).

Cluster		Statement	Bridging value mean (SD)	Importance mean (SD)	Feasibility mean (SD)
Preservation of lands ($n = 10–21.75\%$)			0.16 (0.13)	4.56 (0.68)	3.77 (1.07)
	2	Stop deforestation, river pollution, and land depletion	0.01	4.65 (0.67)	3.7 (1.12)
	1	To preserve the environment, we live in	0.02	4.8 (0.52)	3.85 (0.93)
	16	Urgently prevent human-caused pollution and deforestation	0.07	4.6 (0.79)	3.95 (1.22)
	25	Ensure the preservation or restoration of soil quality	0.13	4.55 (0.69)	3.9 (1.12)
	9	Awareness, appreciation, and preservation of nature	0.15	4.65 (0.59)	3.85 (1.08)
	26	Ensure the preservation or recovery of biodiversity	0.15	4.5 (0.76)	3.7 (1.12)
	24	Ensure the *preservation or recovery of springs* and others	0.16	4.5 (0.60)	3.75 (1.05)
	14	There is sustainable development	0.20	4.55 (0.77)	3.7 (1.15)
	12	Learn new sustainable ways to use natural resources	0.28	4.2 (0.85)	3.55 (1.14)
	40	Rescue of deforested areas, using native species, carried out by the indigenous	0.49	4.8 (0.61)	3.85 (1.19)
Protection of demarcated lands ($n = 4–8.70\%$)			0.31 (0.10)	4.58 (0.71)	3.86 (1.23)
	31	Prevent making a profit from the cost of indigenous life	0.20	4.55 (0.76)	3.85 (1.31)
	39	Ensure and monitor compliance with laws	0.26	4.5 (0.69)	3.75 (1.21)
	45	New land demarcation	0.34	4.55 (0.83)	3.85 (1.27)
	8	Demarcation of indigenous territories for the preservation of the environment	0.46	4.7 (0.57)	4.0 (1.21)
Indigenous health and wellbeing			0.35 (0.14)	4.42 (0.71)	3.98 (1.09)
	32	Promote actions for greater equity in the care given to indigenous peoples	0.08	4.3 (0.73)	3.85 (1.04)
	28	Promote basic sanitation in indigenous communities	0.30	4.6 (0.68)	3.85 (1.23)
	35	Greater assistance for the health of people who live isolated by choice	0.34	4.45 (0.69)	3.95 (1.19)
	37	Promote equity, considering the differences and particularities of each community	0.35	4.45 (0.69)	3.85 (1.08)
	43	Educational initiatives in schools about indigenous peoples and their importance in society	0.38	4.5 (0.51)	4.35 (1.04)
	30	Creation of artisanal wells in the villages through the municipal government, together with FUNAI (National Foundation for indigenous people)	0.43	4.2 (0.95)	3.9 (1.07)
	34	Assistance for mental health care	0.58	4.5 (0.69)	4.1 (1.02)
Ancestral customs ($n = 6–13.04\%$)			0.46 (0.04)	4.55 (0.71)	3.78 (1.14)
	44	Create laws that respect the ancestry and territoriality of indigenous peoples	0.39	4.5 (0.69)	3.75 (1.16)
	36	Guarantee the basic health rights of the indigenous population, considering social, cultural and language aspects	0.46	4.65 (0.59)	4.00 (1.07)
	38	Change in laws for the protection and rights of indigenous peoples	0.48	4.45 (0.83)	3.65 (1.31)

(Continued)

TABLE 2 (Continued)

Cluster		Statement	Bridging value mean (SD)	Importance mean (SD)	Feasibility mean (SD)
	13	Implement policies that help guarantee the exclusive rights of indigenous peoples to lands already demarcated	0.51	4.6 (0.75)	3.7 (1.03)
Global and national actions ($n = 6$–13.04%)			0.61 (0.13)	4.45 (0.71)	3.63 (1.24)
	19	Implement environmental protection laws	0.40	4.45 (0.69)	3.9 (1.25)
	10	Review of global guidelines related to the environment	0.48	4.3 (0.86)	3.55 (1.14)
	11	Taxation of countries that negatively interfere with environmental changes	0.59	4.25 (0.79)	3.2 (1.40)
	20	Government to prevent clandestine mining in indigenous lands	0.66	4.7 (0.47)	3.8 (1.20)
	15	Respect environmental legislation	0.75	4.4 (0.75)	3.55 (1.23)
	29	Receive public resources, whether technological, material, financial and human for the preservation and recovery of the environment	0.75	4.6 (0.60)	3.75 (1.21)
Indigenous rights ($n = 5$–10.90%)			0.64 (0.23)	4.53 (0.67)	3.87 (1.17)
	33	Respect indigenous peoples and their struggle	0.33	4.10 (0.83)	3.90 (0.79)
	7	Respect the rights of indigenous peoples	0.52	4.55 (0.69)	4.05 (1.23)
	6	Fight with us so that the rights of indigenous peoples are respected	0.53	4.60 (0.50)	3.80 (1.23)
	22	Ensure the livelihoods of indigenous peoples	0.84	4.50 (0.83)	3.75 (1.06)
	23	Ensure the right to ancestral territory	0.97	4.55 (0.76)	3.80 (1.09)
Collective living ($n = 4$–8.70%)			0.71	4.15 (0.94)	3.53 (1.24)
	5	Respect the life of the environment	0.36	4.60 (0.68)	3.95 (1.05)
	41	Mankind come to love nature as the mother who bears him fruit	0.77	4.00 (0.92)	3.1 (1.29)
	42	Live collectively, knowing that one depends on the other and that everyone depends on nature	0.84	4.15 (0.93)	3.25 (1.12)
	46	Integrate indigenous knowledge to address environmental changes caused by climate change and land scarcity	0.87	3.85 (1.09)	3.8 (1.36)
Respect ($n = 6$–13.04%)			0.75 (0.14)	4.36 (0.79)	3.75 (1.09)
	27	Recognize and understand indigenous Peoples as stewards of the earth	0.59	4.25 (0.79)	3.75 (1.12)
	3	Respect the territory of indigenous Peoples	0.64	4.8 (0.41)	4.00 (1.02)
	4	Respect sacred territory	0.67	4.65 (0.59)	4.05 (1.05)
	21	Understand that the environment is sacred	0.76	4.10 (0.91)	3.4 (1.14)
	18	Ensure medicinal herbs	0.87	4.20 (0.89)	3.65 (1.09)
	17	Ensure traditional food	1	4.15 (0.81)	3.65 (1.08)

4.1.1. Respect, culture, and the role of young people

The students articulated the need for respect regarding their indigenous knowledge and relationships with nature which affects their health and wellbeing (14, 15, 25). Due to climate change impacts, many are unable to fully observe traditions tied to ancestral lands and this enforced inobservance can cause adverse impacts to health and wellbeing. Students discussed at length the need to understand that the earth is a source of indigenous identity, which is inextricably linked to the overall state of health and wellbeing of indigenous communities (1, 8, 27). Indigenous and Western scholarship alike has advocated for the integration and respect of indigenous worldviews, to link up diverse pathways of knowing and to address environmental events brought upon by

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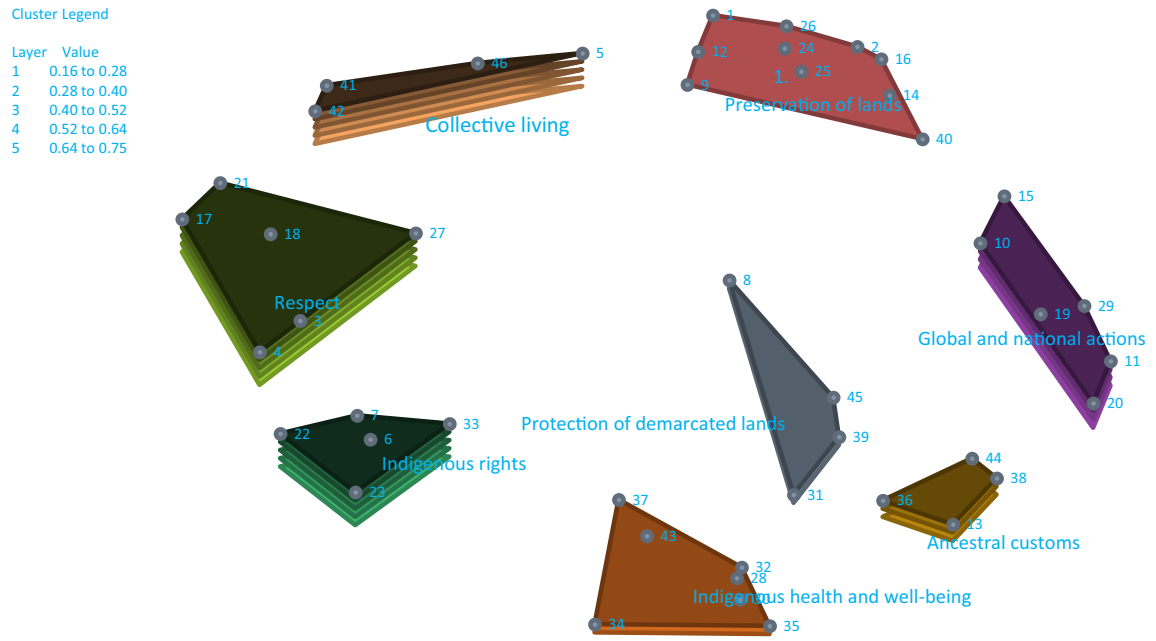

FIGURE 1
Cluster concept map showing the factors that indigenous university students felt could influence the protection of the survival of the indigenous peoples from climate change.

climate change and wider disparities (1, 8, 27). The statements illustrated the gravity of the underrepresentation of indigenous voices in legal and political matters. They also reflected a strong perception of the need for systemic actions to address indigenous–non-indigenous inequalities to sustain and protect indigenous rights. The participatory exercise of CM created an inclusive space to advocate for a response to safeguard their communities. While indigenous young people are some of the most vulnerable people globally and are often disproportionately affected by political decisions, they are excluded from decision-making processes (14, 15, 27). The inclusion of young people is an important catalyst in policy and program advancement, as it offers an intergenerational perspective to support present and future generations vulnerable to the immediate and distal impacts of climate change (28–31).

4.1.2. Brazilian context

The Brazilian Federal Constitution (1988) recognizes indigenous possession of the land as original, that is, before the creation of the Brazilian Federation (32). Legislation such as *"Marco temporal das terras Indígenas"*, however, has made this challenging as it encouraged territorial and land disputes, caused social and economic instability, and promoted violence against indigenous peoples on their native lands (33). Brazil has seen slow progress toward the implementation of legislation that promotes and protects the rights of indigenous peoples and their lands (34–36). This issue dominated many of the statements from participants as they felt there was an urgent need for action (5, 13). While government action and global and national actions were rated highly important, participants were less likely to rate the actions as feasible. This is likely to reflect the doubts acquired from the slow progression and the political climate created by former President Jair Bolsonaro at the time of this study (37). To safeguard their communities, indigenous peoples have been encouraging the implementation of alternative means associated with technological innovations that integrate traditional knowledge and enhance the capacities of pro-environmental and indigenous-oriented organizations (38). There has been some progress on this through funding bodies, such as the Brazilian Amazon indigenous-Podaali, that aim to promote the implementation of socio-environmental policies (34). However, efforts from multisectoral stakeholders to achieve system-wide changes remain patchy (35).

4.1.3. Considerations for international conversations

The need for implementation of international legislation for environmental protection was a prominent topic in the students' discussions. Globally, indigenous peoples fight to protect their ancestral lands and to mitigate harmful impacts of climate change (1, 12, 28, 35, 36, 39). They are at the center of many discussions on the impacts of climate change and are considered the most responsible communities in environmental preservation (14, 15). According to *Complicity in Destruction IV: How mining companies and international investors drive Indigenous rights violations and threaten the future of the Amazon*, over the last 5 years, miners received a total of US$ 54.1 billion in financing from American, Brazilian, and other international investors. Additionally, US$ 14.8 billion was invested in research applications overlapping indigenous lands (40). There was stark awareness in the students' discussion of the global impact of the destruction of the Amazon

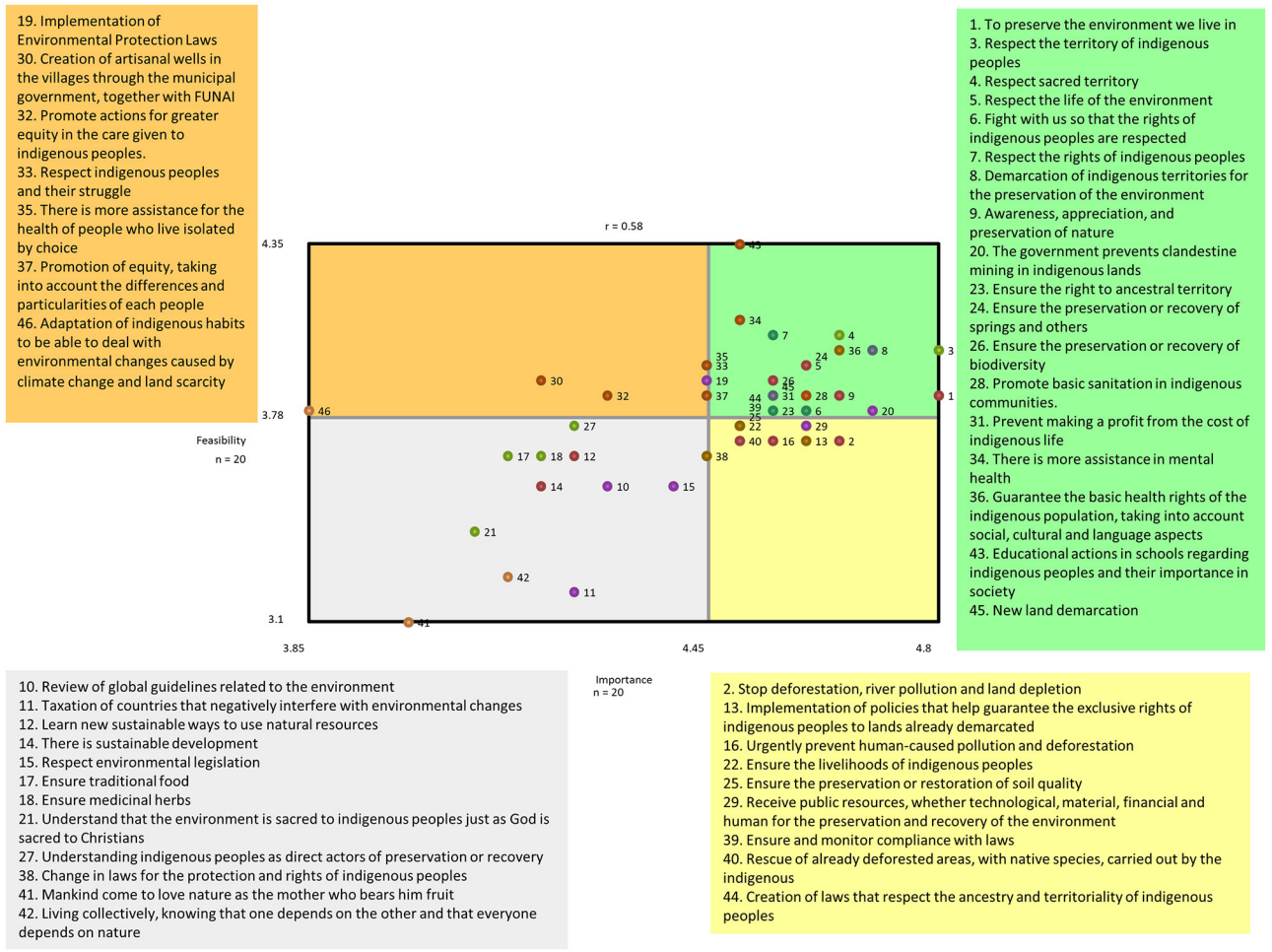

FIGURE 2
Go Zone map showing mean ratings for importance and feasibility for each statement. The colors of each point illustrate which cluster the statements belong to.

Forest by influential international stakeholders. They discussed the Amazon as a vital source of biodiversity and the role it plays in regulating the earth's climate. Its destruction is a significant contributor to greenhouse gas emissions that drive climate change (35). Land restitution is being/or has been addressed in some parts of the globe. For example, in Canada, First Nation communities have regained the rights of a portion of the boreal forest east of Lake Winnipeg, one of the world's most intact ecosystems. Along with the provincial and national governments, the First Nations asked UNESCO to recognize the 29,000 km^2 of Pimachiowin Aki or "The land that gives life", as a World Heritage Site, to protect and restore the health of the land and those who rely on it (5, 41). A positive step forward is the international effort to address the legacies of Bolsonaro's reign. The new Brazilian President Luiz Inacio Lula da Silva and governments from other South American countries (Colombia, Guyana, Bolivia, Venezuela, Suriname, Peru, and Ecuador) that share the Amazon forest have recently declared their shared interest in protecting the forest from further exploitation at an Amazon forest summit in August 2023.

4.2. Strengths and limitations

While there was 100% retention of students throughout each stage of the concept mapping process, a larger and more diverse sample size representing more ethnicities from different villages and young people who are not at university would have enriched the interpretative value. A key strength of the study was the use of concept mapping which is a participatory method. Indigenous students generated the ideas and agreed on priorities. The visual conceptualization of ideas appealed to them and encouraged the discussions on the survival of their communities. Championing young indigenous voices is critical for charting the path to the sustainable development of interventions for system-wide changes.

4.3. Future directions

Indigenous health and wellbeing was the important factor identified in the context of climate change and the survival of

indigenous peoples. Global epidemiological research has shown a widening of health inequalities between indigenous and non-indigenous populations. The divide is illustrated by shorter life expectancies at birth, persistent chronic disease, higher rates of sexually transmitted disease, maternal and infant mortality, and teen pregnancies, compared to non-indigenous (16). Students discussed the need for improving access to healthcare, particularly in relation to mental health, with an emphasis on intercultural models of care. In Brazil, there is emerging support for indigenous-specific health system reform, with an emphasis on holistic perspectives and stakeholder participation (39). National policies in Brazil, such as the National Policy for the Care of Indigenous Peoples, aim to address the poor socioeconomic conditions among indigenous communities and increase access to primary care (40). The policy has, however, been criticized for failing to integrate indigenous traditional knowledge (17). In comparison with Australia and New Zealand, there is less engagement of indigenous peoples in the development of intercultural health programs in Brazil. Services for indigenous communities in Brazil are often provided by non-indigenous visiting practitioners. Relocation to urban centers for employment is also common due to the lack of capacity of indigenous communities. The Brazilian Institute of Geography and Statistics (IBGE) reported that in the census of 2010, 49% of the total population of Brazilian indigenous lived in urban centers, outside demarcated indigenous lands (1).

5. Conclusion

The study aimed to capture the perspectives of indigenous university students on climate change and the survival of indigenous peoples in Brazil. They identified the key factors as preservation of lands, protection of demarcated lands, indigenous health and wellbeing, ancestral customs, global and national actions, indigenous rights, collective living, and respect. The students shared important and feasible changes that can be implemented to safeguard their communities. The knowledge from this study underpins a recently funded study (led by the authors) that will co-develop interventions with multisectoral partners to protect the health and wellbeing of indigenous youths in Brazil. The continuity of community–academic partnerships and capability building of young indigenous researchers are important considerations in indigenous research.

Data availability statement

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

Ethics statement

This study was approved by National Research Ethics Commission (CONEP), protocol CAAE 36372820.0.0000.8027 from May 25th, 2021. The studies were conducted in accordance with the local legislation and institutional requirements. The participants provided their written informed consent to participate in this study.

Author contributions

AG, SH, PJ, ID, and AV coordinated the study, edited, and revised the manuscript. JS, MR, and LB analyzed the quantitative data and wrote the first draft of the manuscript with additions from XZ and LR. All authors were involved in designing the study. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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Greenway interventions effectively enhance physical activity levels—A systematic review with meta-analysis

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Background: Previous studies have examined the impact of greenway interventions on physical activity (PA); however, the results have been inconclusive. In order to address this issue, our study conducted a systematic review with meta-analysis to thoroughly evaluate the evidence and determine the effectiveness of greenway interventions in promoting PA.

Methods: We conducted a comprehensive search of literature databases, such as Web of Science, EMBASE, PubMed (via Medline), Cochrane Library, and Scopus, up to June 15, 2023. To synthesize the available evidence, we performed a meta-analysis using a random effects model. The quality of the included studies was assessed using the criteria developed by the Agency for Healthcare Research and Quality and the Newcastle-Ottawa Scale.

Results: A total of 9 publications were identified, involving 6, 589 individuals. The overall quality of most included studies was rated as moderate to high. Our study found that the greenway was effective in promoting PA among participants. Specifically, active travel (AT) showed a standard mean difference (SMD) of 0.10 [95% confidence interval (CI): 0.04 to 0.17], moderate-to-vigorous PA had an SMD of 0.11 (95% CI: 0.02 to 0.20), and total PA had an SMD of 0.14 (95% CI: 0.06 to 0.21). We also observed significant differences in AT levels among participants based on greenway characteristics, exposure distance, exposure duration, and male-to-female ratio.

Discussion: Newly developed or upgraded greenways have been shown to effectively promote PA. Additionally, research suggests that the longer a greenway has been in existence, the greater the benefits it provides for PA. As a result, the construction of greenways should be recognized as an effective public health intervention.

KEYWORDS

greenway, physical activity, active travel, environment, meta-analysis

1 Introduction

The WHO defines physical activity (PA) as any movement of the body that requires energy expenditure and is produced by skeletal muscles (1). PA not only improves physical health but also enhances mental and social wellbeing (2). According to the latest global estimates, more than 80.0% of adolescents and 27.0% of adults fail to meet the recommended levels of PA set by the WHO (3, 4). Moreover, the COVID-19 pandemic has led to an increase in sedentary behavior (5), exacerbating the already prevalent issue of insufficient PA (6).

Physical inactivity is a significant public health concern that affects individuals throughout their lives and imposes a substantial socioeconomic burden.

The built environment is a significant factor in determining PA levels (7). Multiple studies have consistently shown a positive association between the built environment and PA. It is particularly noteworthy that interventions that focus on improving pedestrian and bicycle transportation, as well as land use and environmental design, have been successful in promoting PA (7, 8). This highlights the importance of creating environments that encourage an active lifestyle. Creating PA-friendly built environments should be prioritized in the field of international health. Specifically, the development of green spaces, such as greenways and parks, within the built environment, is considered an intervention that has the potential to increase PA levels among both children and adults. These green spaces can provide attractive surroundings, easy accessibility, opportunities for social interaction, stress reduction, and essential amenities and infrastructure (9). In recent years, there has been an increasing number of studies examining the relationship between greenways and PA, but the results have been inconsistent. Xie et al. (10) conducted a study that showed a positive influence of a large-scale greenway on both moderate-to-vigorous PA (MVPA) and overall PA. However, Burbidge and Goulias (11) discovered an unexpectedly negative impact on both total PA and walking frequency 5 months after the trail's construction. Moreover, West and Shores (12) found no significant differences in walking, moderate activity, or vigorous activity between the experimental and control groups before and after the greenway's construction. Given the conflicting results, additional research is required to determine the impact of greenway interventions on PA. Furthermore, only four articles have conducted systematic reviews on the relationship between green space interventions (such as greenways, parks, and similar interventions) and PA, and they have reported promising findings (9, 13–15). However, the studies examining greenway interventions included in these reviews are limited to European and American countries, and there is a lack of quantitative evidence. With the significant increase in published research on greenways and their impact on PA, especially including studies conducted in Asian countries and several notable cohort studies published since 2019 (10, 16–18), an updated and comprehensive approach is necessary. The meta-analytic approach offers a statistically robust and objective method of combining diverse empirical findings, expanding the generalizability and significance of conclusions beyond the constraints of individual studies (19). Thus, our aim, through a systematic review with meta-analysis, was to quantify the association between greenways and PA, thereby offering valuable insights for both future academic research and policy-making.

2 Methods

This meta-analysis was conducted in accordance with the Cochrane Collaboration Handbook recommendations (20). The article adheres to the PRISMA reporting checklist (21). The analyses were based on previously published studies, thus ethical approval or patient consent was not required.

2.1 Search strategies and study selection

An exhaustive literature search was conducted to investigate the relationship between greenways and PA. The search was conducted without any language or publication date restrictions and included relevant studies from the inception of each database up to June 15, 2023. The databases used for the search included Web of Science, EMBASE, PubMed (via Medline), Scopus, and the Cochrane Library. The search was comprehensive and involved combining medical subject headings (MeSH), "Emtree" index terms, and free words using Boolean logic operators. The search terms used encompassed "physical exertion," "motions," "walking," "bicycling," "greenway," and "greenways," among others. The complete search strategy is provided in Appendix 1.

To identify additional potentially relevant studies, we employed a comprehensive search strategy. This involved manually searching the reference lists of relevant published studies, screening top journals in the research area (e.g., Landscape and Urban Planning, Transportation Research Part D: Transport and Environment), reviewing gray literature, and examining significant international academic proceedings. The titles and abstracts retrieved from the initial search were efficiently managed using NoteExpress 3.2 (Aegean Sea Software, Beijing, China). The literature screening process was conducted independently by two researchers, with any discrepancies resolved with the assistance of a third researcher. Duplicate studies were automatically excluded using software functions, and studies unrelated to greenways and PA were removed based on their titles and abstracts. The full texts of the remaining relevant studies were obtained and further screened based on inclusion and exclusion criteria. Finally, the selected citations were cross-validated by the two independent researchers to ensure the inclusion of eligible studies. Throughout the screening process, a third researcher provided supervision.

2.2 Eligibility criteria

The studies included in the analysis were required to meet the following criteria.

2.2.1 Populations

The study population consisted of individuals aged 16 and above, residing at different distances from the greenway. There were no restrictions based on gender, health status, or nationality. A sampling process, which involved multiple stages and either stratification, systematic selection, or random selection, was employed to choose the study participants.

2.2.2 Interventions

We included studies that evaluated the impact of developing or upgrading greenways on PA levels of individuals living near these areas. The interventions involved converting existing roads or trails into greenways, which consisted of a combination of bicycle paths and walking trails. These greenways also provided convenient facilities and appealing landscapes (10). Additionally, some studies

focused on the creation of entirely new greenways, which were added to existing ones along rivers (22).

2.2.3 Outcomes

The primary outcome measurements included active travel (AT), which encompassed walking and cycling. Previous studies have confirmed the benefits of AT in reducing health risks by promoting PA levels (23–25). The secondary outcome measurements consisted of MVPA, which includes both moderate-intensity PA and vigorous-intensity PA performed at a metabolic equivalent of task (MET) >3 (1). Additionally, total PA, representing the cumulative PA over the past seven-day period, was also assessed. Various measurement approaches were utilized to evaluate the change in outcomes from baseline to endpoint.

2.2.4 Study design

Our study consisted of population-based longitudinal research and repeated cross-sectional studies. We excluded studies that met the following conditions: (1) studies with inaccessible full-texts or data; (2) studies with a research design limited to one experimental group, review or narrative articles, study protocols, or qualitative studies; (3) studies that did not provide specific data on the distance from the participant's residence to the greenway; (4) multiple publications from the same study population analyzing data with the same exposures and outcomes during the same time periods.

2.3 Data extraction and quality assessment

Two researchers independently collected vital data from each study and recorded it in a pre-designed Excel spreadsheet. The data included information such as authors, year of publication, study design, region, sample size, female ratio, exposure duration or completion date of the greenway, and PA outcome(s). In cases where the required information was not available in the original studies, efforts were made to contact the authors of potential studies and obtain the necessary data.

The researchers chose specific scales according to the study design of the included studies. Cross-sectional studies were evaluated using the Agency for Healthcare Research and Quality (AHRQ) meta-analysis of statistics assessment and review instrument, while cohort studies were assessed using the Newcastle-Ottawa Scale (NOS) (26). The AHRQ meta-analysis instrument consists of 11 items, detailed in Supplementary Table S2 (27). Each item was assigned a binary score of either "1" if it met the criteria or "0" if it did not. The evaluation and classification of article quality were carried out using the specified criteria: low quality (0–3), moderate quality (4–7), and high quality (8–11). Furthermore, the NOS consists of eight items that are divided into three dimensions: selection, comparability, and outcome, as outlined in Supplementary Table S1 (28). Items falling under the selection and outcome categories can receive a maximum of 1 star each, while comparability permits a maximum of 2 stars. Articles that achieved a NOS score of 7 or higher were classified as "high quality," while those scoring below 7 were considered "low quality."

2.4 Statistical analyses

In the initial stage, we conducted a conventional pairwise meta-analysis for each comparative trial included in the study (20). For numerical variables, we extracted the mean difference (MD) and standard deviation (SD) of the change from baseline. Alternatively, we transformed the variables into a standardized format. Additionally, we collected exposure estimates with significant effects from the included studies or used estimates from other studies that were most comparable. For instance, He et al. (17) examined the impact of proximity to a greenway on walking outcomes. Participants residing at varying distances (0–1 km, 1–2 km, 2–3 km, 3–4 km, and 4–5 km) were included in the study. The results showed a significant increase in walking time among participants living within a 2-kilometer radius of the greenway. For the meta-analysis, the estimates for the exposed group (0–1 km and 1–2 km) were combined separately from the estimates for the unexposed group (2–3 km, 3–4 km, and 4–5 km), taking into account other relevant studies included in this review (10). To capture the final intervention effect of the study, we extracted data for the last follow-up period from the study that reported estimates for two follow-up periods (29). In cases where the exposure period of the greenway intervention was not specified, we calculated the intervention effect by considering the time difference between the opening of the greenway and the last follow-up as the exposure duration.

To ensure a conservative approach, we utilized a random-effects model (30). This allowed us to calculate the standardized mean difference (SMD), pooled effect sizes, and corresponding 95% confidence interval (CI), taking into account the diverse units of measurement used in the study outcome indicators (31). The quantitative pooled analyses were performed using the random effect model and I-V heterogeneity approach (20). I^2 statistics were utilized to assess statistical heterogeneity, where values of 25, 50, and 75% were considered as indicating mild, moderate, and high heterogeneity respectively. A $P > 0.1$ was considered as indicating non-statistically significant heterogeneity (32). Additionally, potential bias in small studies was evaluated using a comparison-adjusted funnel plot, which examined publication bias, selective reporting, or other biases. The quantitative Egger's test was conducted to identify the presence of $P < 0.05$ (33). Subgroup analyses were conducted to investigate observed heterogeneity and explore statistically significant differences among the studies. The variables of interest included exposure duration (≥12 months and <12 months), male-to-female ratio (≥1 and <1), exposure distance (within 1.00 km from the greenway and 1.00 km-2.00 km from the greenway), greenway characteristics (including blue space and no blue space), total sample size (>450 and ≤450), and region (Europe and America, China and Australia). The statistical analyses were performed using version 14.0 of the STATA software.

3 Results

3.1 Literature selection

In this study, we conducted a comprehensive search across various databases and sources, resulting in a total of 1, 429

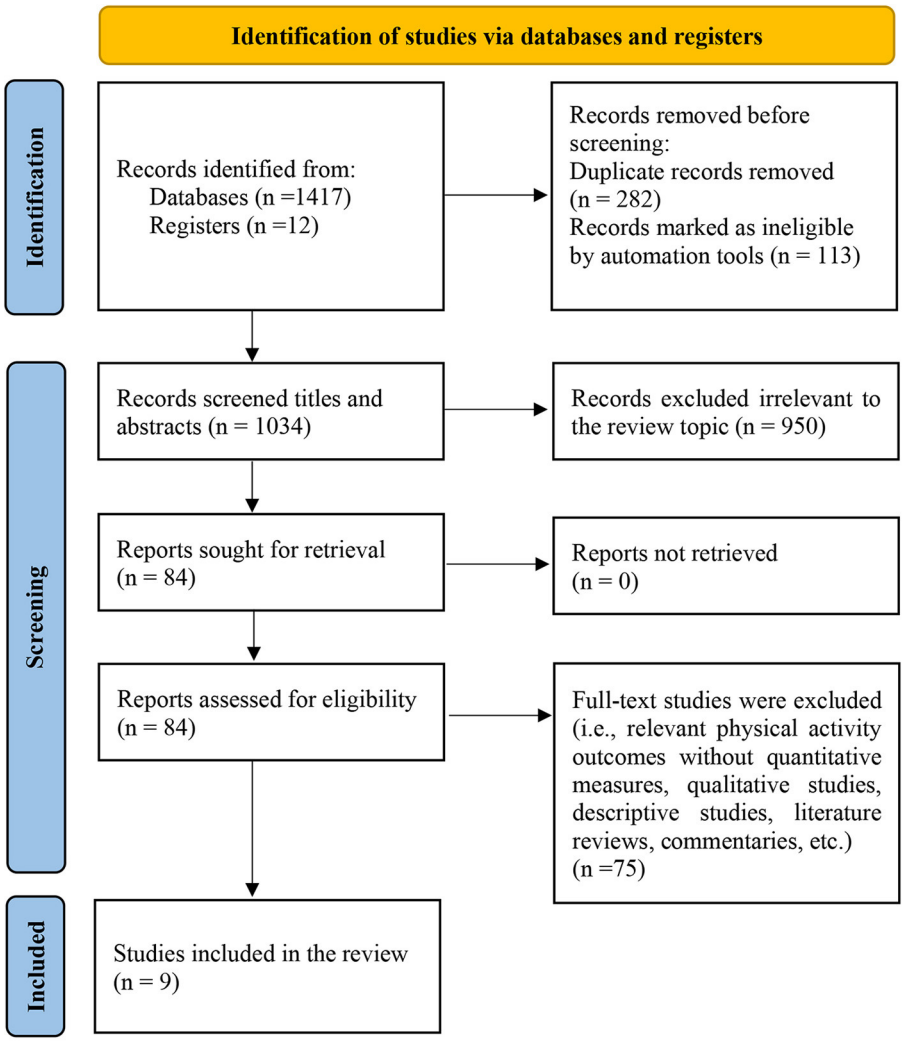

FIGURE 1
Flowchart of study selection.

publications (Figure 1). After removing duplicate articles and conducting an initial screening of titles and abstracts, we identified 84 relevant articles for further evaluation of their full texts. Out of these, 75 publications were excluded from the analysis due to reasons such as the absence of quantitative measures for relevant PA outcomes, qualitative studies, descriptive studies, literature reviews, commentaries, and others. Finally, our analysis included 8 longitudinal studies and 1 repeated cross-sectional study (10, 12, 16–18, 22, 29, 34, 35).

3.2 Characteristics of studies

Table 1 provides a summary of the characteristics of the nine studies analyzed in this research. The sample sizes varied between 169 and 1, 465 participants. The duration of the interventions ranged from 3 months to 30 months. Out of these studies, five (55.6%) were published since 2019 (10, 16–18, 34). In seven (77.8%) of the studies, the female participants exceeded the male participants (10, 16–18, 22, 29, 34). The included studies had sample populations from five countries, with four studies (44.5%) from North America (12, 16, 18, 22), two studies (22.2%) from Asia (10, 17), two studies (22.2%) from Europe (29, 34), and one study (11.1%) from Oceania (35). Out of the nine studies included in this analysis, five of them incorporated blue space (10, 17, 22, 29, 34). These studies used self-reported tools to assess PA. In total, more than five different self-reporting methods were utilized, including validated methods such as the Global PA Questionnaire (34) and non-validated questionnaires developed by researchers (12, 22).

3.3 Quality of the included studies

In this review, the NOS assessed eight longitudinal studies. The review included four high-quality studies with scores ranging between 7 and 8 (10, 16–18), as well as four low-quality studies with a score of 6 (12, 22, 29, 35). Supplementary Table S1 presents a comprehensive explanation of the NOS assessment

TABLE 1 Characteristics of the included studies.

Sources	Study design	Sample	Female (%)	Survey time	Exposure duration or completion date of the greenway	Intervention	Region	Outcomes and measures
Merom et al. (35)	LS	450	44.9	2000.11; 2001.03	Three months	The construction of a 16.5-km-long Rail Trail cycleway and publicity	Australia	Walking, cycling (the 1999 National PA survey)
West and Shores (22)	LS	169	52.4	2007.12; 2008.12	Eleven months	5 miles of greenway were developed and added to an existing greenway along a river	USA	Walking, MPA, VPA (RDQ)
Goodman et al. (29)	LS	1,465	54.5	2010.04; 2012.04	Opened in September 2011.	Building or improvement of walking and cycling routes including two traffic-free bridges and an informal riverside footpath turned into a boardwalk	United Kingdom	Walking, cycling, all PA (IPAQ)
West and Shores (12)	LS	203	41.7	2009.11; 2011.11	One year	1.93 miles of greenway were developed and added to an existing greenway	USA	Walking, MPA, VPA (RDQ)
Frank et al. (16)	LS	524	55.3 (IG); 59.0 (CG)	2012.10–2013.03; 2014.10–2015.03	Opened in June 2013	The 2 km greenway is a major active transportation corridor	Canada	MVPA (IPAQ-SF)
Xie et al. (10)	LS	1,020	56.6	2016.04; 2019.04	Two and a half years	The East Lake greenway that was the original vehicle roads were converted into a 102-km-long greenway	China	MVPA, overall PA (IPAQ-SF12)
Frank et al. (18)	LS	524	55.3 (IG); 59.0 (CG)	2012.10–2013.03; 2014.10–2015.03	Opened in June 2013	The 2 km greenway is a major active transportation corridor	Canada	Cycling (a two-day travel diary)
He et al. (17)	LS	1,020	56.6	2016.04; 2019.04	Two and a half years	The East Lake greenway that was the original vehicle roads were converted into a 102-km-long greenway	China	Walking (IPAQ-SF12)
Hunter et al. (34)	Repeated CS	1,214	55.5	2010; 2017	Six months	Provision of a 9 km urban greenway along the course of 3 rivers and publicity	United Kingdom	Total PA (GPAQ)

All PA, overall PA, and total. PA, cumulative physical activity over the preceding seven-day period; CG, controlled group; CS, cross-sectional study; GPAQ, the Global Physical Activity Questionnaire; IG, intervention group; IPAQ, the International Physical Activity Questionnaire; IPAQ-SF, the short form International Physical Activity Questionnaire; LS, Longitudinal study; MVPA, moderate-to-vigorous intensity physical activity; MPA, moderate physical activity; PA, physical activity; RDQ, Researcher Developed Questionnaire; USA, the United States of America; VPA, vigorous physical activity.

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process. Additionally, a repeated cross-sectional study was given a moderate-quality rating with an AHRQ score of 7 (34). Supplementary Table S2 contains information on the evaluation of quality.

3.4 Primary outcome

3.4.1 Active travel

Six studies utilized questionnaires to report outcome indicators associated with AT, involving a total of 4, 081 participants (12, 17, 18, 22, 29, 35). The findings revealed that individuals residing in close proximity to the greenway exhibited a higher likelihood of experiencing improvements in their AT (SMD = 0.10, 95% CI: 0.04 to 0.17; I^2 = 0.0%, $P_{heterogeneity}$ = 0.49) (Table 2, Forest plot: Supplementary Figure S1). Additionally, the symmetrical funnel plot results and a *P*-value of 0.94 from the Egger regression test indicated the absence of significant publication bias (Supplementary Figure S2).

3.5 Secondary outcomes

3.5.1 Moderate-to-vigorous PA

Four studies, with a total of 2, 242 participants, reported MVPA (10, 12, 16, 22). The analysis showed significant differences in MVPA (SMD = 0.11, 95% CI: 0.02 to 0.20; I^2 = 0.0%, $P_{heterogeneity}$ = 0.90) (Table 2, Forest plot: Supplementary Figure S3). The funnel plot demonstrated high symmetry, indicating the absence of publication bias. Additionally, Egger's test results (P = 0.63) suggested a low risk of publication bias (Supplementary Figure S4).

3.5.2 Total PA

Three studies, involving a total of 3, 699 participants, reported on total PA (10, 29, 34). The analysis showed significant differences in total PA (SMD = 0.14, 95% CI: 0.06 to 0.21; I^2 = 0.0%, $P_{heterogeneity}$ = 0.55) (Table 2, Forest plot: Supplementary Figure S5). The funnel plot displayed high symmetry, suggesting the absence of publication bias. Additionally, the results of Egger's test (P = 0.49) indicated a minimal risk of publication bias in this analysis (Supplementary Figure S6).

3.6 Subgroup analyses

Subgroup analyses were conducted on the primary outcome measure of AT, using different variables of interest. The results indicated statistically significant differences among the subgroup items. For instance, participants who were exposed to the greenway for 12 months or longer (SMD = 0.11, 95% CI: 0.01 to 0.21, I^2 = 0.0%, $P_{heterogeneity}$ = 0.86) showed a significant improvement compared to those exposed for <12 months (SMD = 0.10, 95% CI: −0.03 to 0.23, I^2 = 41.1%, $P_{heterogeneity}$ = 0.17). Similarly, participants within the range of 1.00–2.00 km from the greenway (SMD = 0.11, 95% CI: 0.02 to 0.20, I^2 = 24.8%, $P_{heterogeneity}$ = 0.26) showed a similar result compared to those within 1.00 km from the greenway (SMD = 0.08, 95% CI: −0.07 to 0.23, I^2 = 0.0%, $P_{heterogeneity}$ = 0.95). The combined effect sizes for the subgroup analyses, calculated using the random-effects model, are presented in Table 2.

4 Discussion

To the best of our knowledge, this study represents the first comprehensive meta-analysis investigating the impact of greenway interventions on PA levels in participants. Our findings indicate a small but significant increase in PA levels among individuals residing near the greenway following the implementation of greenway interventions. Moreover, our results highlight that longer exposure to greenways, greenways incorporating blue space, intervention groups with a higher proportion of women, and participants living within a 2 km radius of a greenway experienced notable improvements in AT.

4.1 Main findings of the meta-analysis

This analysis suggests that greenway interventions have a positive impact on AT, MVPA, and total PA levels among nearby participants. This effect can be attributed to three primary factors. Firstly, the attractiveness of green spaces encourages individuals to engage in PA more frequently (36). Previous reviews support this view, indicating a strong association of 0.75 between green spaces and MVPA, highlighting the potential of landscape improvements to enhance the PA experience and promote PA (9, 15, 37). Secondly, greenways serve as linear infrastructure, connecting parks, open spaces, and public facilities, and have been shown in previous reviews to be associated with promoting PA and improving AT (37, 38). Furthermore, as traffic-calmed pathways, greenways enhance AT and promote PA by improving actual or perceived safety on the roads (39). Previous reviews have shown both positive and null associations between green space interventions, including greenways, parks, and similar interventions, and PA outcomes (13, 14). Our review demonstrates a substantial increase in PA among participants as a result of greenway interventions. This positive effect can be attributed to the distinctive spatial characteristics of greenways. The study highlights that individuals across all age groups show a preference for semi-natural green spaces over formal parks and sports fields (40). Greenways, due to their proximity to residential areas and provision of opportunities for walking in a semi-natural environment, are highly popular and greatly contribute to their utilization rates (40, 41). However, it is worth noting that certain studies have reported no significant rise in PA among participants residing near greenways (12, 34). This phenomenon can be attributed to a range of factors, including external influences such as social trends and psychological variables, as well as internal factors like the accessibility and openness of the greenways (34, 42). It is imperative to conduct further research to substantiate the existing findings, which should encompass comprehensive explanations of potential external and internal factors that may have a significant impact on the applicability of these findings to diverse urban areas. While this review primarily concentrates on individuals aged 16 and above,

TABLE 2 Primary results based on various outcomes and subgroup analyses.

Meta-analyses outcomes	Meta-analyses variables	No. of studies	No. of residents		Pool effect size	Heterogeneity	
			IG	CG		I^2 (%)	*P*
Primary outcome	AT	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
Secondary outcomes	MVPA	4	1,444	798	0.11 (0.02 to 0.20)	0.0	0.90
	Total PA	3	2,733	966	0.14 (0.06 to 0.21)	0.0	0.55
Subgroup analysis based on the primary outcome of AT							
Exposure duration	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Above or equal 12 months	3	1,135	606	0.11 (0.01 to 0.21)	0.0	0.86
	Below 12 months	3	1,475	865	0.10 (−0.03 to 0.23)	41.1	0.17
Male to female ratio	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Above or equal 1	2	513	393	0.09 (−0.13 to 0.31)	58.1	0.09
	Below 1	4	2,097	1,078	0.12 (0.04 to 0.19)	0.0	0.96
Exposure distance	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Within 1.00 km	2	332	358	0.08 (−0.07 to 0.23)	0.0	0.95
	1.00 km−2.00 km	4	2,278	1,113	0.11 (0.02 to 0.20)	24.8	0.26
Greenway characteristics	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Include blue space	3	1,858	793	0.12 (0.04 to 0.21)	0.0	0.96
	No blue space	3	752	678	0.08 (−0.06 to 0.22)	37.4	0.19
Total sample size	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Below or equal 450	3	606	466	0.09 (−0.08 to 0.25)	37.5	0.19
	Above 450	3	2,004	1,005	0.12 (0.04 to 0.20)	0.0	0.88
Region	Overall	6	2,610	1,471	0.10 (0.04 to 0.17)	0.0	0.49
	Europe and America	4	1,461	891	0.11 (0.02 to 0.19)	0.0	0.98
	China and Australia	2	1,149	580	0.11 (−0.07 to 0.29)	61.8	0.07

AT, Active Travel (walking and cycling for transportation); CG, controlled group; CI, confidence interval; IG, intervention group; MVPA, moderate-to-vigorous intensity physical activity (include moderate-intensity physical activity and vigorous-intensity physical activity); PA, physical activity; Pool effect size: pooled SMDs (95% CI); SMD, standard mean differences; Total PA: cumulative physical activity during the past seven-day period.

future studies should also explore the influence of greenways on PA among children and adolescents.

In the subgroup analysis of the primary outcome (AT) in this meta-analysis, statistically significant differences were observed within intervention effects in various subgroups. These groups included factors such as exposure duration, gender ratio, exposure distance, and greenway characteristics. Specially, when examining the subgroup based on exposure duration, participants with exposure duration exceeding 12 months exhibited a significant improvement in AT compared to those with exposure duration of less than 12 months. This finding suggests that longer greenway exposure time is associated with greater improvements in AT, because it takes time for behavior to settle (14). Shorter time periods are insufficient for accurately capturing habitual activity behaviors, as there is significant variability in weekly activity behaviors within individuals throughout the year and across different seasons (43). In order to assess the maintenance of behavior change, it is crucial to have a minimum exposure duration of 1 year (13). In addition, the effectiveness of interventions was found to be higher in populations with a greater proportion of females, which may be attributed to individuals' activity. Intercept surveys conducted with users of urban multiuse trails revealed that the majority of respondents reported utilizing the trails primarily for recreational activities (44). Recreational users in this study were found to cover longer distances and had a higher utilization rate of the trails. Surveys also indicated that females were more likely than males to visit the trails for leisure purposes, exercise, and to experience nature (44, 45). When considering intervention distance thresholds, it was discovered that effective thresholds fell within the range of 1.00 to 2.0 km, with distances <1.00 km being ineffective. In the studies, participants were divided into two groups: exposed and unexposed. This categorization was based on the proximity of their homes to green spaces, which was crucial for evaluating the effectiveness of the green space intervention. Previous research has indicated that individuals living near green spaces are more likely to engage in PA (46). However, there may be a threshold beyond which the distance to the green space starts to affect behaviors such as walking (47). This threshold is typically considered to be ∼1.20 to 1.60 km, which is equivalent to about a 15-min walk, and is commonly referred to as a rule of thumb in walkability

literature. On the other hand, other studies have found that most participants tend to frequently visit green spaces within 2.0 km of their homes (45, 48). The study outcomes may be influenced by thresholds below 1.00 km or exceeding 2.00 km, as participants may experience similar effects from green spaces. It is important to note that distance thresholds can vary depending on factors such as the type and size of the green space, cultural and social context, and the specific domain of PA. Hence, depending on the context, a range of 1.00–2.00 km may be appropriate for identifying exposed and unexposed groups. However, it is essential to emphasize that some studies have found no association between PA and the objective distance to green spaces (49), suggesting that objective distance may not be the most suitable indicator when exploring the relationship between PA and green space. Careful consideration should be given to selecting thresholds in future studies on greenspace interventions. Subgroup analysis revealed that greenways with water had larger intervention effects compared to those without water. Water is widely recognized as an important and attractive landscape element, and people generally prefer areas with water sources. It has been observed that natural scenes with water have a more positive impact on preference and rating judgments (50). Additionally, previous research has found positive associations between water features such as lakes and streams and PA in green spaces (49). Therefore, the study suggests that improving green corridors along canals could be an effective approach to increasing greenway usage and promoting PA (51). Consequently, incorporating water features in greenways may prove to be an effective intervention strategy for promoting PA among participants.

4.2 Strength and limitations

Our systematic review conducted a quantitative analysis to investigate the association between greenway interventions and participants' levels of PA. The main strength of our review lies in its emphasis on studies that evaluated PA levels before and after the greenway intervention, offering evidence to support a causal relationship between the greenway intervention and PA. No significant heterogeneity was observed, indicating that the effect size was representative of the overall population. However, this study did have some limitations that were identified. Firstly, the meta-analysis utilized outcome indicators from questionnaires, which may introduce recall bias or social desirability bias. Secondly, the majority of the studies included in this paper relied on natural experiments. While natural experiments are considered reliable and practical for studying the causal effects of the built environment on PA (52), a recent review assessing the risk of bias in natural experiments highlighted certain methodological limitations in key bias domains (53). Thirdly, the studies included in this review used various methods to select participants, assess greenway exposures, and measure outcomes. This diversity in methods could potentially introduce bias in the pooled estimates. Additionally, the studies in this review collected data on overall PA rather than specifically focusing on PA associated with greenways, which could also bias the findings. Therefore, it is important to exercise caution when interpreting the findings of our study, considering the aforementioned limitations.

4.3 Implications

In our research, we found that the greenway intervention had a small effect size on participants' PA, ranging from $d = 0.10$ to $d = 0.14$ (54). However, it is important to consider the impact of this effect size in real-world settings, which is influenced by participants' baseline PA levels. Previous reviews have demonstrated that effect sizes of $d = 0.19$ and $d = 0.18$ correspond to a weekly increase in PA duration of 15 and 73 minutes, respectively, based on participants' activity levels prior to the intervention (55, 56). The impact of even small effects on public health should not be underestimated, particularly when considering the cumulative effect over time and across large populations (57). Research indicates that even minor increases in PA resulting from the greenway intervention can lead to substantial health and cost benefits at the population level, as well as broader societal advantages (58). Therefore, caution is advised when interpreting the reported effects of the intervention.

Residents residing near a greenway exhibit a higher likelihood of participating in AT and engaging in MVPA. Such participation not only enhances physical fitness and reduces sedentary behavior but also fosters both physical and mental wellbeing. In order to encourage residents, particularly those living within a 2 km radius of a greenway, to increase their utilization and awareness of these pathways, it is recommended to implement initiatives like publicity campaigns, educational programs, and other related activities. These efforts will contribute to elevating PA levels within the community population. From a perspective of green space planning and design, it is imperative to enhance the accessibility of greenways, optimize their placement, incorporate them with blue spaces, and take into account the diverse preferences of residents. Considering the enduring beneficial effects of greenways on PA, local governments should give priority to their construction, refurnishment, and upkeep in urban green space planning to enhance public engagement and utilization. Furthermore, recent analyses on social return on investment have underscored the potential for greenways to generate positive economic returns (59, 60). Hence, the implementation of greenways for PA, encompassing their design, construction, and sustainable maintenance, emerges as a financially viable approach. Ultimately, greenways, when integrated into a comprehensive transportation and environmental system, possess substantial capacity to foster personal and communal wellbeing while also facilitating sustainable urban progress.

5 Conclusions

In this systematic review with meta-analysis, we present the most recent evidence indicating a small but meaningful increase in PA among individuals living near greenways. Moreover, subgroup analyses reveal that the impact of greenway interventions differs depending on specific moderating factors and environmental conditions. By objectively synthesizing existing research on greenway interventions and PA, this

review offers valuable insights into the effects of green spaces on PA, highlighting the potential of greenways in promoting public health. Based on these findings, it is recommended that city managers and policymakers include greenways in their overall green space strategy, recognizing their construction and management as a crucial intervention for promoting public health. However, this review also highlights some limitations in current research designs. To improve the quality and accuracy of future studies, researchers in this field should strengthen the rigor of their experimental methods, concentrate on specific types of PA, and utilize advanced analytical techniques such as machine learning to reveal the intricate dynamics of greenway utilization.

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 authors.

Author contributions

YD: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Validation, Writing – original draft. JL: Data curation, Formal analysis, Investigation, Methodology, Resources, Software, Validation, Writing – review & editing. QC: Conceptualization, Methodology, Supervision, Validation, Writing – review & editing.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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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.2023.1268502/full#supplementary-material

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Construction of the "Full Path" of restorative effects on older adults' mental health in parks under seasonal differences: taking Changchun as an example

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With the aging and older adults' mental health problems in China, more attention has been paid to the restorative environment. As an important restorative environment in the city, the mental health restorative effect of park environment has been confirmed. However, further exploration is needed to determine whether winter parks have positive effects, their differences from non-winter parks, and the specific pathways of these effects. Therefore, this study constructed a "full path" for the restorative effects of older adults' mental health in parks under seasonal differences, including four components: perceived environment, affective feedback, behavioral feedback, and restorative effect, forming four pathways. Based on this, this study obtained 211 and 240 sample data in winter and non-winter parks, and verified the validity of various hypotheses and mediation paths using structural equation models. It found that: (1) overall restorative effects existed in different seasons; (2) in winter, perceived environmental assessment was not a direct antecedent of restorative effects, and affective feedback and Moderate and Vigorous Physical Activity (MVPA) feedback were important mediating factors, and the chain mediated pathway existed; (3) in non-winter, both direct, indirect and chain mediated effects existed, and affective feedback and Low Physical Activity (LPA) feedback were important mediating factors. Based on this, this study divided parks into "affective inducing" and "behavioral promoting" types, and proposed corresponding planning priorities to positively intervene in planning and design practices.

KEYWORDS

full path, restorative effects, older adults' mental health, parks, seasonal differences

1 Introduction

China is entering an aging society at the fastest pace in history and with a large population of older adults. By 2027, China will transform from an "aging" society to an "aged" society. At the same time, the health challenges faced by older adults in China require more attention. A report showed that nearly one-third of the older adults in China suffer from depression, and

the overall prevalence of mild cognitive impairment (MCI) among people aged above 65 is 20.8% (1). Based on this, it can be seen that the situation of aging and mental health issues in China is not optimistic. In 2022, 15 departments including the China Health Commission jointly issued the "14th Five-Year Plan for Healthy Aging," emphasizing the need to optimize the social environment for healthy living of older adults, better meet their health needs, improve their health level, and extend their healthy life expectancy.

Urban parks have been proven to be one of the main environments for older adults' activities (2, 3), and their health restorative effects have been widely recognized both domestically and internationally. With the expansion of the dimension of health recovery, the restorative effect of mental health has received more attention. The restorative effects of mental health in parks include both long-term and short-term effects. For one thing, people living near parks and frequently using parks have lower levels of mental stress (4, 5). For the other, 30 min after entering the park, the visitor's depressive mood is significantly improved (6). The longer they spend in the park, the better their mental state is restored, including restoring attention levels, improving emotional states, enhancing self-worth, and subjective well-being (7–10). Frequent access to the short-term recovery effect of parks can also reduce the risk of mental illness (11). The above effects can have a certain positive guidance on residents' lifestyles, but for urban planning practitioners, how to implement them in design practice still seems a bit confusing. Therefore, it is even more important to effectively decompose the effect process, positively intervene in the effect path, and implement it in spatial characteristics and elements.

The existing paths of park restorative effects can be roughly divided into two types: direct effects and indirect effects. On the one hand, the former is a direct relationship between the establishment of park environment and restorative effects. Kaplan et al. found that park natural landscape and waterscape have the greatest impact on mental health recovery, and their scale, layout and types have significant differences in the impact of restorative effects (12, 13). Ulrich et al.'s research has shown that people in a suppressed state can significantly alleviate their psychological stress after viewing the park environment (14, 15). These two results are also corresponding to attention recovery theory (ART) and stress relief theory (SRT) in restorative environment. Some studies also focused on the extraction of spatial features and the summary of spatial perception, which can be understood as subjective perception evaluation induced by physical environmental, namely "perceived environment." For example, some studies divide spatial feature factors into natural factors, perceptual factors, activity factors, and resting factors based on the constituent elements of plants, water bodies, and facilities (16, 17).

On the other hand, indirect effects are the restorative effects exerted by park features through intermediary pathways, which can be roughly divided into discussions on "affection" and "behavior." One is the discussion involving environmental preferences and place attachment, both of which are individual affect expressions of the environment, hence collectively referred to as "affective feedback." This mainly includes a simple impact path of "environmental preference → restorative effect" and a composite impact path of "environmental preference → place attachment → restorative effect." Environmental preference can be understood as an individual's willingness to choose a certain environment (18), and its correlation with restorative assessment has been proven by many studies, and it has been found that the higher the preference, the stronger the restorative effect of the environment (9). Place attachment describes the emotional relationship between people and places, and people give value to the place through the stable accumulation of emotions (19). Geographers usually believe that individuals need to gain a sense of belonging, self-esteem, and security through their attachment to the place (20), which is related to health and well-being (21, 22). The higher the attachment to the environment, the higher its restorative effect (23). Meanwhile, according to Biophilia Hypothesis, humans are inherently inclined to focus their attention on life or its processes (24), instinctively generating demands or preferences for nature, thereby exhibiting adaptive attachment. Some studies have also confirmed the relationship between environmental preference and place attachment in forests, parks, and natural recreational areas (25, 26). It is worth emphasizing that older residents are more likely to be attached to green spaces than young people. This may be related to the fact that older adults have less mobility than young people and have more time to visit nearby green spaces (27). This is also an important reason for incorporating affective feedback into this study.

For another, there was more research on the discussion of "behavior" mediator. It has shown that as people age, regular exercise can prevent frailty in old age by enhancing muscle strength and quality, as well as maintaining bone density, independence, and vitality (28). Appropriate exercise is associated with better quality of life, positive emotions, and mental health levels (29). In the discussion of behavior patterns, the focus was on the classification of behavior types. Behaviors in parks can be divided into passive, active, and mixed behaviors based on spontaneity (30); necessary activities, spontaneous activities, and social activities according to the content (31); low, medium, and high intensity behaviors according to the intensity of exercise (32). Behavior, as feedback of environmental perception, can directly affect restorative effects. At the same time, the exploration of indirect pathways is also related to the "Cognition-Affect-Behavior" process, which is the ABC attitude model. This model believes that cognition (C) is the antecedent of emotion (A) and behavior (B), and behavior (B) is the decision result of cognition (C) and emotion (A) (33), commonly seen in consumer behavior and psychological therapy. In the field covered by this article, the park environment can be regarded as a service product, while the perceived environmental evaluation is a cognitive result, and the visitors' feelings, decision-making, and recovery processes in it are similar. This can help research establish the relationship between affect and behavior.

In addition, existing research focused more on non-winter parks, and although some studies have now shifted their focus to winter, it still appeared insufficient. Especially, older adults in cold regions are affected by extreme weather conditions and exhibit more significant depressive and seasonal emotional problems. Therefore, the discussion of winter in cold regions is also of great significance. Some studies have shown that plant landscapes covered with snow in winter exhibit different visual effects and may also have a restorative effect (34). Winter and summer also have attention recovery effects, and seasonal plant visual changes can enhance the recovery effect (35). However, most of these studies focused on young people and were conducted through VR experiments. Laboratory experiments cannot truly reflect individuals' feelings in the environment and have certain limitations.

Overall, there are three issues with relevant research: Firstly, most existing research explored a single path from a certain perspective, and mostly discussed behavior, lacking a detailed breakdown of

psychological processes and a comprehensive grasp of the entire path. Secondly, the exploration of winter parks has not yet been in-depth, especially in cold winters. It cannot be ignored that even in cold climates, the need for residents to get close to nature remains unabated. It is still unknown whether winter parks in cold regions have psychological health restorative effects and their differences from non-winter ones. Thirdly, most studies did not differentiate the target group, and research methods may not be universally applicable. The cognitive process and affective feedback of older adults are different from those of young people, and their specificity should be considered in spatial representation and research methods. For example, older adults have higher requirements for environmental safety, social interaction (3), and are more inclined toward familiar environments (36). Based on these, this study focused on the recovery effect of older adults' mental health, coordinating winter and non-winter, and intended to clarify the effects and processes of winter and non-winter park environments on the psychological health recovery of older adults. The former can help designers clarify the health recovery ability of winter and non-winter park environments, while the latter can help further understand the key points of optimizing park environments under seasonal differences.

Additionally, psychological processes have complex mechanisms, which are more evident in the restorative effects of mental health in park environments. After integrating existing research pathways, it can be found that environmental preferences are the result of environmental perception processes. If the discussion starts from physical environmental stimuli, it is necessary to discuss the spatial perception process of "sensation-perception-cognition" (37–40). Among this, perception refers to the interpretation of signals received by human organs through the heart and mind. Cognition is a process of information processing that includes sensation, perception, memory, thinking, imagination, and language. Considering that the entire psychological process is too complex to be clearly divided, and that existing research does not have a clear division of spatial constituent elements, characteristic elements, and perceptual elements, in order to avoid such problems, this study started with "perceptual environment" to discuss and simplify the psychological process. Furthermore, based on ABC theory of "cognition-affection-behavior" (41), this research shifted its focus to the discussion of different seasons, affective and behavioral directions, and constructed a "full path" for the restorative effect of mental health for older adults, in order to grasp the entire process of its implementation and positively intervene in park design practice from different stages.

2 Methodology and material

2.1 Site selection and data collection

This study took Changchun, a typical cold regional city, as an example. Changchun has distinct seasonal differences. Based on the definition of Chinese meteorological standards and monthly standards, combined with the actual situation in 2023, the average temperature in winter (November–April of the following year) is −9.3–1.8°C, and the average temperature in non-winter (May October) is 12.5–24.5°C. And NH Park, CC Park, SL Park, and LD Park as the research locations were selected (Figure 1). These above parks are all representative parks in Changchun, and are characterized by free admission, rich natural elements, convenient transportation, high density of surrounding communities, and high reachability and vitality of older adults.

The survey consists of three parts, divided into winter and non-winter periods. The first part is behavioral observation and semi-structured interviews. Based on the Mutually Exclusive Collectively Exhaustive (MECE) principle, 32 and 43 older adults were selected for in-depth interviews in winter and non-winter parks respectively, to understand the spatiotemporal behavior characteristics of them in different seasons of these parks, as well as the important spatial elements and features they consider important. The second part is a factor analysis survey. Based on the results of interviews, small-scale surveys were conducted, collecting 108 and 113 questionnaires in winter and non-winter respectively, to extract, classify, and name factors. The third part is the effect path survey, which is divided into pre survey and formal survey. Based on the pre survey results, the questionnaire items were revised. The winter formal survey was conducted from January to March 2022, and the non-winter formal survey was conducted from August to September 2022. Each park randomly selected 55–60 questionnaires, and the respondents obtained a total of 211 winter valid samples and 240 non-winter valid samples.

To sum up, observation, interview, SD, and factor analysis methods were used to determine observational and latent variables of perception factors, while the self-rated health approach was used to measure the restorative effects of mental health. Due to the unique characteristics for older adults, methods for obtaining physiological indicators through physiological testing equipment and common pressure methods are not applicable. Therefore, considering the cognitive style of older adults, discussing the restorative effects of psychological health through self-assessment based on psychological perception perspective is more feasible and practical. Unlike other objective measurement methods of physiological indicators, self-assessment of health is a subjective evaluation of the research object's own health status (42), which is not stimulated or interfered with by the external environment and has high representativeness and sensitivity. Currently, this method is commonly used in many research reports of the World Health Organization to measure the quality of life and health status of older adults (43, 44). In terms of effect path analysis, this study used Structural Equation Modeling (SEM) for multiple mediation analysis, which quantifies observation variables to explore the motivators and pathways of the restorative effects of mental health for older adults in parks (Figure 2).

2.2 Path assumption

Based on ABC theory, this study proposed two hypotheses (Figure 3): Hypothesis 1, corresponding to the overall effect, the specific content is: H1. Winter parks can significantly positively affect the restorative effect of older adults' mental health. Hypothesis 2, corresponding to the decomposition of effect paths, specifically including: Path I (direct effect), H1e. Perceived environmental assessment can directly and significantly positively affect the restorative effect of mental health for older adults; Path II: H2. Perceived environmental assessment can significantly and positively affect the affective feedback for them in parks, and H3. Affective feedback can significantly and positively affect the restorative effect of

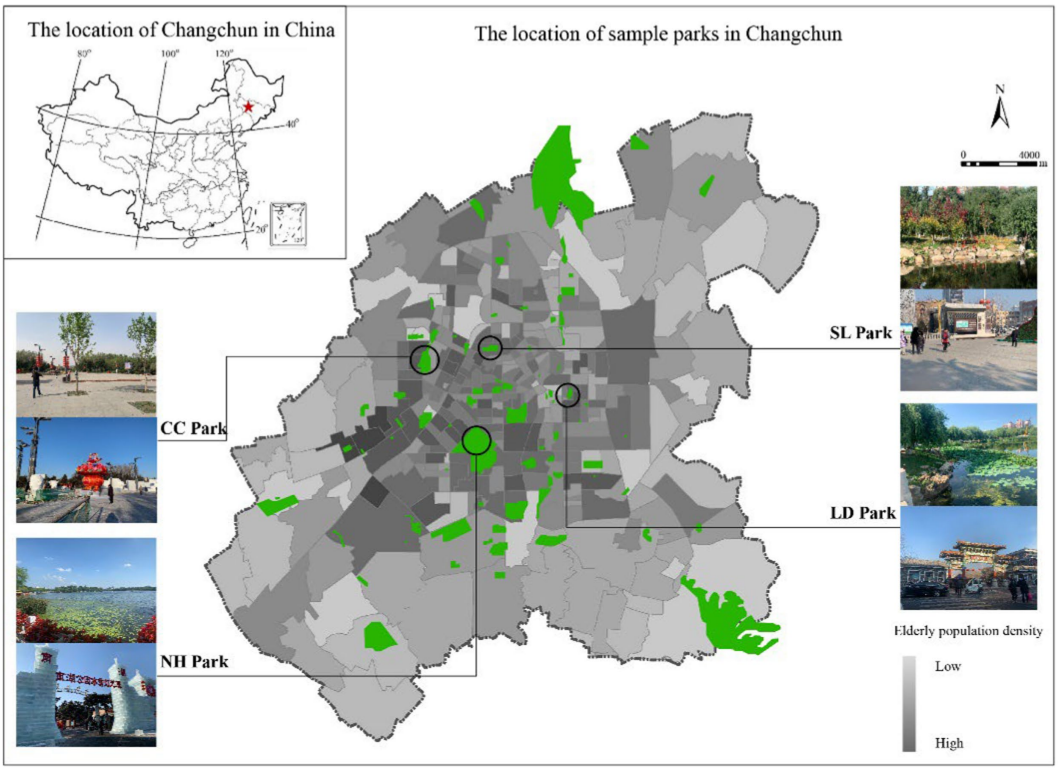

FIGURE 1
Sample parks location. Source: Modified from the data provided by Changchun Urban and Rural Planning and Design Institute.

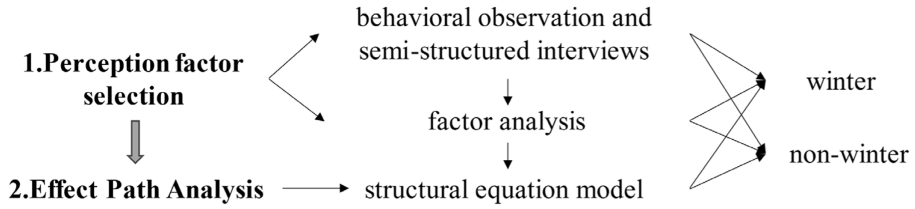

FIGURE 2
Research process and methods.

older adults' mental health; Path III: H4. Perceived environmental evaluation can significantly and positively affect the behavioral feedback for them in parks, and H5. Behavioral feedback can significantly and positively affect the restorative effect of mental health for them; Path IV: H6. Affective feedback can positively affect behavioral feedback. Additionally, this research assumed that the mediating pathways of "perceived environment → affective feedback → restorative effect," "perceived environment → behavioral feedback → restorative effect," and "perceived environment → affective feedback → behavioral feedback → restorative effect" all exist.

2.3 Variable settings

Firstly, based on the interview results, the study obtained the spatial composition and characteristic elements that older adults consider important in the park, and preliminarily classified the influencing factors into 16 in winter and 20 in non-winter. Then, it classified and named these influencing factors through Semantic Differential (SD) method and factor analysis method. The survey conducted reliability and validity tests, and then exploratory factor analysis (EFA) was used to extract 5 dimensions, with feature root values greater than 1. The variance interpretation rates of the five rotated factors in winter were 20.152, 19.824, 15.787, 14.803, and 14.148%, respectively. The cumulative variance interpretation rate after rotation was 84.71%. In non-winter, those were 18.826, 16.676, 12.694, 12.680, and 11.942%, and the cumulative variance interpretation rate after rotation was 72.817%. The results indicated that these factors are evenly distributed and can explain most of the differences in variables. And then, factors were named based on the properties and characteristics of each dimension, and were divided into five categories: (I) sense of security factors, (II) sense of comfort factors, (III) sense of interest factors, (IV) sense of convenience factors, and (V) sense of belonging factors (Table 1). These five types

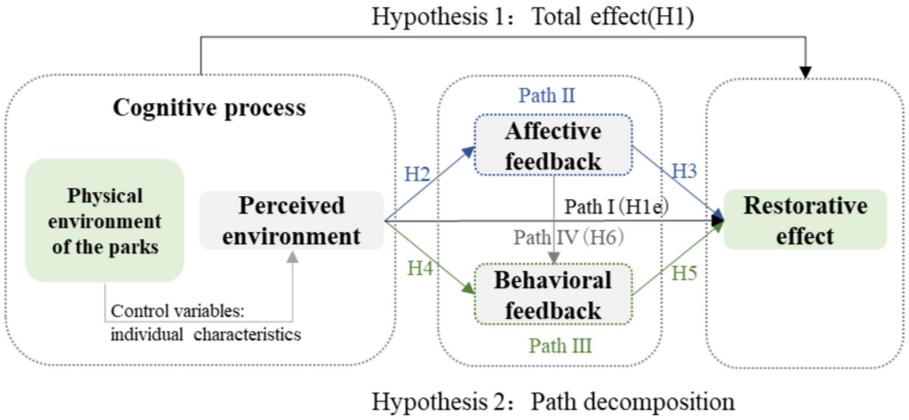

FIGURE 3
Research hypothesis.

of factors are also similar to Meta's proposal based on the classic concept that good public spaces should have characteristics (45), which indirectly confirms the rationality of the classification and naming of perceptual environmental evaluation factors.

On these grounds, this study used these five types of factors as latent variables for perceived environmental evaluation, affective and behavioral feedback as mediating variables, older adults' individual characteristics as control variables, and the restorative effects as dependent variables to establish a full path model. In the affective feedback stage, based on the pathway of "environmental preference → place attachment → restorative effect," place attachment is usually divided into two dimensions: place dependence (PD) and place identity (PI) (46). PD is a functional attachment that focuses on the function of a place to meet individual needs, emphasizing an individual's sense of belonging to the place. PI is an affective attachment that leans more toward the internal emotional connections between individuals and places, emphasizing the shared values, attitudes, thoughts, beliefs, etc. Some studies have also shown that place attachment mainly affects people's attitudes and behaviors toward the environment through the mediating role of place identity (47). Therefore, E1 Preference (degree of liking for the environment), E2 Dependence (degree of belonging and functional attachment to the environment), and E2 Identity (degree of identification and affective attachment to the environment) were selected as the observation variables for affective feedback. In the behavioral feedback stage, based on the distinction between function and exercise intensity, a reasonable and observable classification method with unified standards was selected, which includes Moderate and Vigorous Physical Activity (MVPA), and Low Physical Activity (LPA) (48). Moreover, based on behavioral observation results, the study divided MVPA into M1 Walking and running behaviors (fast walking, jogging, etc.), M2 Fitness behaviors (Tai Chi, equipment sports, ice skating, etc.), M3 Recreational behaviors (square dance, etc.), and LPA into L1 Group leisure behaviors (playing cards, playing chess, etc.) and L2 Individual leisure behaviors (walking dogs, resting, etc.).

The observation of restorative effects was conducted through a self-assessment approach, drawing on the revised ROS scale by Kaplan et al. (12), and the World Health Organization's Physical and Mental Health Scale (WHO-5). Six items were formed, including R1—relieving stress, R2—restoring attention, R3—improving emotions, R4—reducing loneliness, R5—increasing energy, and R6—eliminating fatigue and improving sleep quality. Each item of this survey was scored by the Likert scale 1–5 points. At the end, the collection of information on older adults themselves was added, including gender, age, frequency of visiting parks, and length of stay time.

3 Results

3.1 Descriptive statistics

211 and 240 valid sample data were obtained in winter and non-winter, respectively (Table 2). In the winter sample data, the proportion of older adults under 70 years old was relatively large, accounting for 60.62%; female accounted for 63.03%; the majority of older adults visited the parks 2–4 times a week, being 46.44%; 74.41% of them stayed in the parks for less than 2 h. In non-winter, female accounted for 62.92%; 42.92 and 32.91% were, respectively, aged 61–69 and > 70; 83.34% older adults visited the parks more than twice a week; and 40.42 and 35.00% of samples stayed in the parks for 1–2 h and more, respectively.

3.2 Reliability and validity test

After SPSS and AMOS analysis, the overall reliability and validity of the pathway study were obtained. Cronbach α for winter and non-winter data showed that both overall and partial reliability were good. The data also passed KMO and Bartlett's tests, and the KMO values were both greater than 0.9, indicating that it can be further analyzed. Then, this study conducted confirmatory factor analysis (CFA) to test the rationality of each sub item setting within the model (Table 3). Firstly, standard load coefficient values are usually used to represent the correlation between factors and analysis items (measurement items). The results showed that the standard load coefficients were all greater than 0.7 and significant, indicating a strong correlation between observed variables and latent variables;

TABLE 1 Load factor after rotation.

Dimension name	Winter	Factor loading					Non-winter	Factor loading				
		1	2	3	4	5		1	2	3	4	5
I sense of security factors	A1 Flat paving			0.465			A1 Flat paving				0.643	
	A2 Reasonable height difference			0.572			A2 Reasonable height difference				0.819	
	A3 Reasonable lighting facility settings			0.896			A3 Reasonable lighting facility settings				0.784	
	A4 Clear direction			0.831			A4 Clear direction				0.498	
II sense of comfort factors	S1 Pleasant acoustic environment		0.707				S1 Pleasant acoustic environment					0.848
	S2 Fresh air		0.778				S2 Fresh air					0.742
	S3 Comfortable leisure facilities		0.773				S3 Comfortable leisure facilities					0.614
							S4 Good shading conditions					0.643
III sense of interest factors	Q1 Rich plant hierarchy and evergreen plants					0.684	Q1 Rich plant species	0.705				
	Q2 Available water space					0.872	Q2 Rich plant colors	0.788				
	Q3 Rich structures, landscape sketches or ice and snow sculptures					0.641	Q3 Rich plant hierarchy	0.808				
							Q4 Beautiful waterscape	0.769				
							Q5 Rich structures and landscape sketches	0.678				
IV sense of convenience factors	B1 Good functional space reachability	0.889					B1 Good functional space reachability		0.635			
	B2 Adequate activity facilities and space	0.889					B2 Adequate activity facilities and space		0.865			
	B3 Frequently updated and maintained activity facilities	0.745					B3 Adequate leisure facilities		0.613			
							B4 Frequently updated and maintained various facilities		0.606			
V sense of belonging factors	G1 Easily recognized park features				0.861		G1 Easily recognized park features			0.566		
	G2 Good cultural deposition				0.786		G2 Good cultural deposition			0.709		
	G3 Rich activity forms				0.701		G3 Rich activity forms			0.764		

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TABLE 2 Composition of survey samples.

		Winter		Non-winter	
		N	%	*N*	%
Gender	Female	133	63.03	151	62.92
	Male	78	36.97	89	37.08
Age	55–60	56	26.54	58	24.17
	61–69	93	44.08	103	42.92
	>70	62	29.38	79	32.91
Frequency of visiting park	Once a week or less	46	21.80	40	16.66
	Twice to four times a week	98	46.44	112	46.67
	More than four times a week	67	31.76	88	36.67
Length of stay time	Less than 1 h	76	36.02	59	24.58
	1–2 h	81	38.39	97	40.42
	Over 2 h	54	25.59	84	35.00

TABLE 3 Reliability and validity test of winter and non-winter models.

Dimension	Latent variable	Winter			Non-winter		
		Cronbach α	AVE	CR	Cronbach α	AVE	CR
Perceived Environmental Stage	F1 sense of security factor	0.928	0.770	0.930	0.915	0.739	0.918
	F2 sense of comfort factors	0.939	0.839	0.940	0.890	0.626	0.893
	F3 sense of interest factors	0.847	0.665	0.856	0.851	0.545	0.856
	F4 sense of convenience factors	0.919	0.801	0.923	0.912	0.720	0.911
	F5 sense of belonging factors	0.841	0.647	0.845	0.863	0.700	0.872
Affective feedback stage	F6 affective feedback	0.894	0.741	0.895	0.725	0.580	0.734
Behavioral feedback stage	F7 MVPA feedback	0.831	0.632	0.837	0.874	0.714	0.882
	F8 LPA feedback	0.836	0.730	0.843	0.696	0.553	0.711
Recovery stage	F9 restorative effects	0.906	0.630	0.910	0.785	0.510	0.805

secondly, Mean Variance Extraction (AVE) and Combined Reliability (CR) values were used to test the aggregated validity of different dimensions. AVE were all greater than 0.5 and CR were all greater than 0.7, indicating that the aggregated validity of the model was high; in addition, the discriminant validity test was conducted using the correlation matrix between factors, and the model still had good discriminant validity.

3.3 Model fitting results

To make the research results more concise, this study firstly used the average of specific observation variables to measure five perceived environmental factors, and simultaneously formed S1 perceived environmental evaluation by combining the five factors. Then separate F7 and F8 to form H41, H42, H51, H52, and H61, H62 assumptions. Including: H41. F7 can significantly positively affect F9; H42. F8 can significantly positively affect F9; H51. S1 can significantly positively affect F7; H52. S1 can significantly positively affect F8; H61. F6 can significantly positively affect F7; and H62. F6 can significantly positively affect F8. The results of various important fitting indicators have reached a good or acceptable level, proving the usability of the model (49–51) (Table 4). The regression results of the model were shown in Figures 4, 5. As shown in the results, in winter, H1e and H52 were not valid, and the overall effect, path 2, and path 4 assumptions were also valid; in non-winter, H51 and H61 were not valid, and all other assumptions were valid.

Furthermore, the bootstrap (sample = 5,000) automatic sampling method was used to test mesomeric effect, and the results were shown in Table 5. If the confidence range of bootstrap does not contain 0, it indicates that mediating effect exists; if the direct effect does not exist and the mesomeric effect exists, it is completely mediated, otherwise

TABLE 4 List of important fitting indexes of non-winter and winter model.

	$\chi 2/df$	GFI	RMSEA	RMR	CFI	NFI	NNFI
Acceptable range	<3	>0.7	<0.10	<0.05	>0.7	>0.7	>0.7
Winter	2.914	0.754	0.094	0.026	0.858	0.805	0.842
Non-winter	2.426	0.769	0.077	0.011	0.874	0.806	0.857

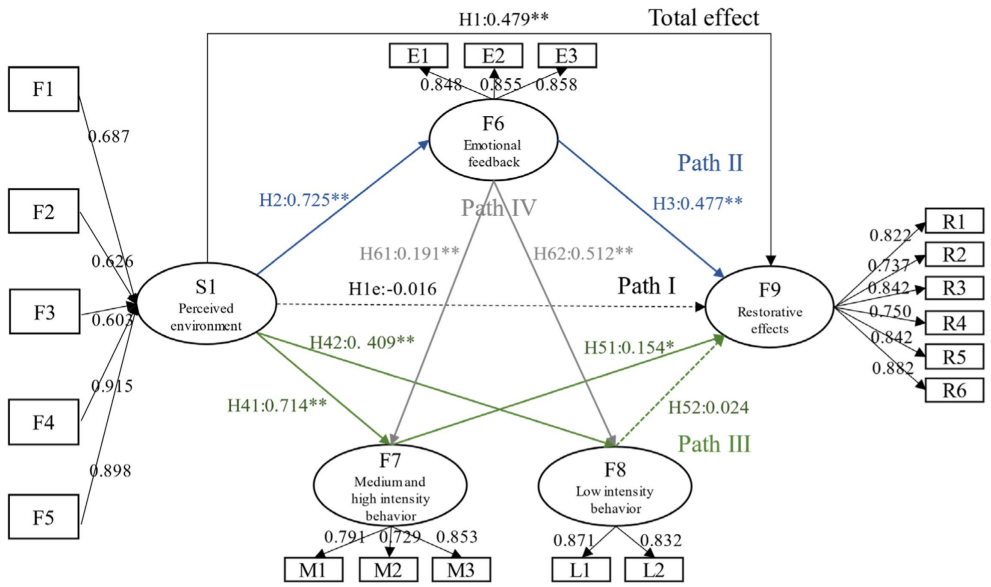

FIGURE 4
Model and path coefficient of the restorative effects in winter parks.

it is partially mediated (52). The results illustrated that in winter, affective feedback and MVPA feedback played a completely mediating role in the recovery effect of older adults, and the mesomeric effect of affective feedback was slightly higher than that of behavioral feedback path; and the chain mesomeric effect of "perceived environment → affective feedback → MVPA feedback → restorative effect" existed. In non-winter, affective feedback and LPA feedback played a partial mediating role, and the effect value of the former was still higher than that of the latter; the chain mediation effect of "perceived environment → affective feedback → LPA feedback → restorative effect" existed.

Based on previous interviews and surveys, it was found that the frequency and duration of older adults visiting parks in winter were lower than those in non-winter. Overall, parks had better restorative effects on older adults aged 61–69 and >70. The higher the frequency of visiting parks and the longer the duration of stay time, the better the affective feedback and the stronger the restorative effect. This was consistent with the conclusion of a case study in Netherlands that the higher the frequency of people visiting urban parks, the closer their connection and attachment to them (53).

In winter, influenced by extreme weather conditions, there were significant differences in spatial perception and temporal spatial behavior among older adults in the parks, especially among women, middle—aged and the very older adults. For example, roads covered with ice and snow can reduce the sense of security for older adults, thus limit their travel possibilities and activity duration. The cold and single landscape in winter can also weaken its visual experience, reducing the frequency of travel to a certain extent. However, interesting and storytelling ice and snow landscapes can enhance spatial attractiveness, promote their preference and attachment to the environment, and thus increase the frequency and duration of visits. Due to biophilia and fitness goals, about one-third of older adults still exercised "in all weathers." This type of older adults' activities in the parks were usually concentrated between 9:00 am to 11:00 am and after 18:00 pm. Daytime activities were mainly about walking, dancing, and equipment sports, while evening activities were mainly focused on dancing. As for non-winter, the park environment was vibrant and shaded by green trees, and the probability of older adults engaging in low-intensity behavior was significantly increased, mainly including sightseeing, rest, taking care of grandchildren, playing cards, and so on. In addition, in terms of spatial distribution, winter had more obvious clustering, and the hot spot spaces were usually adjacent to the entrance and exit and the main road in the parks; in non-winter, it appeared to be more dispersed and built-in, with an increased likelihood of internal space being explored. In summary, the relevant results can indirectly confirm the importance of discussing the restorative effects of parks in different seasons.

4 Discussion

4.1 Discussion on the total effect under seasonal differences

H1 was to verify the total effect of the parks' restorative effect on older adults mental health. The results indicated that even in winter, parks still had restorative effects, with the total effect coefficient of

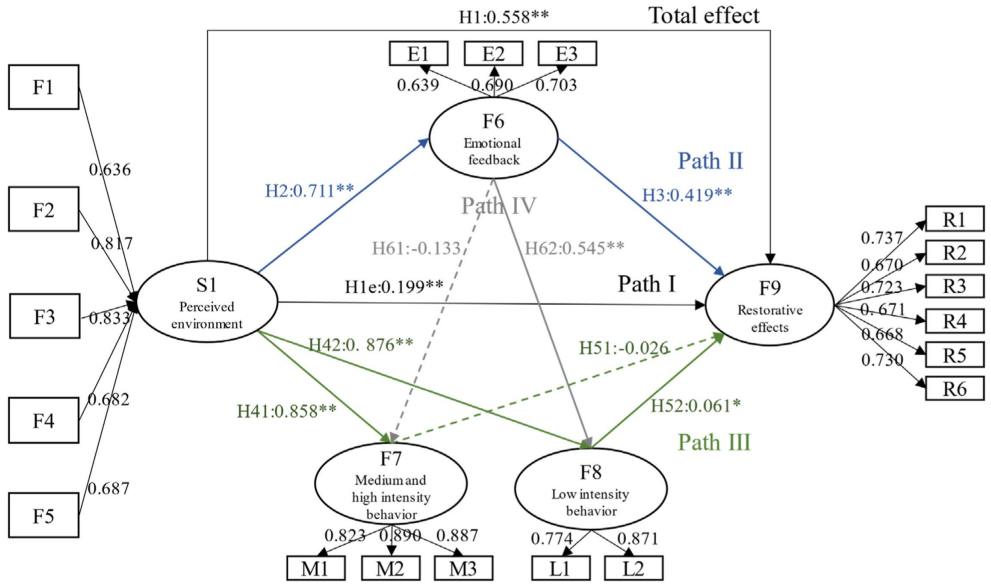

FIGURE 5
Model and path coefficient of the restorative effects of in non-winter parks.

TABLE 5 Intermediary effect test.

		Path	Effect	Boot SE	BootLLCI	BootULCI	*Z*	*p*	Conclusion
Winter	Path II	S1 ⇒ F6 ⇒ F9	0.346	0.059	0.262	0.446	5.888	0.003	Supported
	Path III	S1 ⇒ F7 ⇒ F9	0.110	0.048	0.022	0.209	2.303	0.021	Supported
		S1 ⇒ F8 ⇒ F9	0.010	0.025	−0.037	0.063	0.396	0.692	Not supported
	Path IV	S1 ⇒ F6 ⇒ F7 ⇒ F9	0.021	0.016	0.002	0.050	1.321	0.094	Supported
		S1 ⇒ F6 ⇒ F8 ⇒ F9	0.009	0.027	−0.036	0.055	0.332	0.681	Not supported
Non-winter	Path II	S1 ⇒ F6 ⇒ F9	0.298	0.060	0.310	0.546	4.940	0.000	Supported
	Path III	S1 ⇒ F7 ⇒ F9	−0.022	0.051	−0.130	0.043	−0.050	0.577	Not supported
		S1 ⇒ F8 ⇒ F9	0.053	0.049	−0.017	0.180	1.083	0.279	Supported
	Path IV	S1 ⇒ F6 ⇒ F7 ⇒ F9	0.002	0.006	−0.008	0.019	0.377	0.706	Not supported
		S1 ⇒ F6 ⇒ F8 ⇒ F9	0.024	0.021	−0.008	0.077	1.119	0.263	Supported

0.479; the total effect coefficient of non-winter was 0.558, which was higher than that in winter.

Speaking separately, comparing the correlation coefficients of five types of perceived environmental evaluation factors on restorative effects in winter, the ranking is: F4 sense of convenience factors (0.915) > F5 sense of belonging factors (0.898) > F1 sense of security factors (0.687) > F3 sense of interest factors (0.626) > F2 sense of comfort factors (0.603). (1) Among them, the most important purpose for older adults to visit parks in winter was to exercise, so the coefficient of convenience was the highest in terms of whether the venue was easy to reach, followed by the adequacy of fitness facilities and space. The phenomenon that older adults usually chose to exercise in spaces closer to entrances and exits in the survey may provide some explanation. (2) Among the factors of sense of belonging, the most important was rich forms of activities, followed by whether the park is distinctive. Although each sample park has its representative characteristics, it is particularly evident in LD Park. Many older adults believed that parks with bright colors and ethnic characteristics will be more attractive, and they preferred a lively and familiar atmosphere, which will encourage them to linger and bring more companions. (3) Regarding the factors of sense of security, it was particularly important to have a reasonable height difference design and a smooth and anti-slip paving. In the interview, older adults expressed that it is inevitable to accumulate ice and snow in winter, and pedestrians wear heavy clothes, which makes it very difficult to take steps and other actions. Falling has become one of the important threats to older adults' health, so it is very important to ensure that the floor is not slippery. (4) As for sense of interest, the factors with higher path coefficients were the available water space, rich plant layers and evergreen plants. This was consistent with Kaplan's results, as even in winter, the presence of water and plants is quite important. This also echoed other research findings, such as the fact that a snowless vegetation environment on

streets in winter can help alleviate people's mental fatigue (54); and winter entertainment activities in snowy forests also have psychological recovery effects (55, 56). In the survey, ice and snow sports relying on water were more attractive to older adults men. Besides that, ice sculpture exhibitions similar to NH Park and snow sculpture activities in CC Park can enhance their sense of participation and novelty. (5) About sense of comfort factors, the most important was fresh air. Most older adults said that "exercising every day is to breathe fresh air, otherwise I will feel suffocated." Followed by the sound environment, they said that "if there is music and songs, the mood will be better." And due to the winter climate, they rarely sited and rested outdoors, so the comfort of rest facilities ranked last.

Unlike winter, the ranking of perceived environmental factors in non-winter was: F3 sense of interest factors (0.833) > F2 sense of comfort factors (0.817) > F5 sense of belonging factors (0.687) > F4 sense of convenience factors (0.682) > F1 sense of security factors (0.636). Firstly, the most important elements were plant and water in F3. Green plants can relax the human nervous system, make the body calm, comfortable, and vigorous, which is beneficial for promoting long-term psychological health of older residents (57); the presence of water can enhance the alertness of older adults in parks (58). So that a plant landscape with rich colors, levels, and types, as well as beautiful water features can bring positive visual experience and potential for restoration. It is worth mentioning that older adults showed a high preference for brightly colored landscape. Secondly, the most important comfort factors were fresh air and good shading conditions. The former was similar to the winter results, where "breathing fresh air" is like "exchanging blood" for older adults, and is an important way to rejuvenate oneself, which is similar to "forest bathing" (59). Thirdly, in the sense of belonging factors, the order of each observation variable was the same as in winter, and a lively and familiar atmosphere had more potential for recovery. Fourthly, among the convenience factors, the setting of rest facilities had the highest path coefficient, which was different from winter. This may be related to the behavioral content of older adults in non-winter. Adequate rest facilities can not only provide them with a place to rest, but also provide them with social space. Finally, in F1, the most important still lied in the rationality of vertical and paving design. This was most evident in NH Park, as it is equipped with a plastic walkway, which can enhance the comfort and safety of sports with its cushioning and anti-slip performance.

4.2 Discussion on each effect path under seasonal differences

4.2.1 Discussion on Path I under seasonal differences

Path I, namely the direct impact of perceived environmental assessment on the restorative effect of older adults' mental health. It was indicated that perceived environmental assessment was not the direct antecedent of restorative effects in winter. This was not entirely consistent with existing research conclusions (60), which may be caused by different climate regions and seasons. One of the possible reasons is that the winter landscape in cold regions is single, which cannot provide good visual stimulation and comfortable activity space, resulting in a decrease in the overall subjective perception of environmental evaluation results, and thus the direct effect path cannot be established; another reason may be that although the direct effect of perceived environmental evaluation on restorative effects was negative, the total effect reached 0.479, indicating that winter parks may exert restorative effects more through affective and behavioral feedback.

In non-winter, the direct effect of "perceived environment → restorative effect" was significant, indicating that different elements and features of space can directly have positive restorative effects. Compared to winter, the non-winter park environment is lush, more vibrant, and able to enhance the subjective perception of space by older adults. This is similar to the conclusion in ART theory, where a good space can provide visitors with feelings of being away (getting rid of their current exhausted life state), fascination (naturally captivating), compatibility (providing conditions that are consistent with people's preferences and activities), and extent (its richness and coherence allowing them to fully explore) (61). Consistent with other existing research findings, urban green spaces have a positive impact on visitors' emotions and arousal (9); natural environment can enable people to experience more positive emotions, including satisfaction, happiness, and peace, as well as alleviate negative emotions such as anxiety, fear, and anger (10).

4.2.2 Discussion on Path II under seasonal differences

Path II assumed that the park environment affects the restorative effect of mental health through affective feedback, which was simply the effect path of "perceived environment → affective feedback → restorative effect." This path contained assumptions about H2 and H3. Both winter and non-winter results supported the relevant assumptions in Path II and confirmed the existence of mediation pathway, which was in consensus with the existing research conclusions (62). Among them, the order of the observed variables in affective feedback is: identification > dependence > preference. The possible reason is that identity is a higher-order affective feedback compared to preference and dependence, and residents' functional dependence on space has a positive impact on the formation of affective attachment. Place dependence, as an intermediary element of place identity, can affect people's attitudes and behaviors toward the environment (47), thus having a greater impact on restorative effects.

Further connections have been established between affective feedback and five types of perceptual factors in winter and non-winter, respectively. It was found that both in winter and non-winter, the factors of sense of belonging and sense of interest ranked high in terms of importance. Affections may be more about stimulating feedback through visual dimensions. In terms of spatial cognition methods and approaches, it can be divided into "scientific cognition" and "experiential cognition," as well as "experiential spatial cognition" and "constructive spatial cognition." Scientific and experiential cognition is objective and exclusive, which is the result of abstraction and rationalization of space directly through the senses; Empirical and constructive approaches require the affective participation of cognitive subjects (35). The long-term experience and accumulation of experience make the subjective cognitive role of older adults more prominent. As a result, older adults have a greater preference for familiar environments and stronger feedback on situational triggered affective experiences.

4.2.3 Discussion on Path III under seasonal differences

Path III contained the contents of H4 and H5. The results confirmed that the park environment exerted restorative effects by promoting older adults' behavior, which was consistent with the conclusion in existing studies that behavior can promote restorative effects (58). Differently, the results showed that H52 in winter was not valid, and H51 in non-winter was not. In other words, the restorative effect of the winter park was achieved through mediating pathways that promote older adults MVPA; while in non-winter, it was achieved by promoting LPA.

In winter, due to the influence of climate, older adults must "move" in the park to achieve the goal of physical fitness, so they mainly engage in MVPA. Among such behaviors, older adults tended to engage in more recreational activities, such as yangko dancing, followed by fitness activities such as skating, equipment sports and taichi, and finally, fast walking and jogging. About LPA instead, older adults tended to engage in group leisure activities, such as playing chess, playing cards, etc., while individual leisure activities such as walking and walking dogs came in second place. Correspondingly, in non-winter, older adults were more likely to engage in low-intensity behaviors compared, especially in sightseeing, resting, and other behaviors; among MVPA, equipment sports and dance exercises were the majority.

Similarly, the relationships between different perceived environmental factors and behaviors of different intensities have also been further explored. It was found that there are certain differences in the ranking of the impact of five types of perceived environmental evaluation factors on behaviors of different intensities. On the one side, the top two perceived environmental evaluation factors that affected MVPA were F4 sense of convenience factors and F1 sense of security factors. The main reason may be that when older adults engage in high-intensity behaviors, they pay more attention to the safety of the site, whether there are potential hazards causing physical damage. The convenience and accessibility of the place, as well as the adequacy of facilities and space, are also key considerations, while other factors will only help them improve the enthusiasm and sustainability to a certain extent. On the other side, the main factors that affected LPA were: F5 sense of belonging and F3 sense of interest factors. The possible reason is that low intensity behaviors have relatively small movement rates and amplitudes, and older adults have a stronger ability to perceive the impact of visual dimensions in space. They have a higher demand for bright colored decorations and structures, soundscapes, and odors.

4.2.4 Discussion on Path IV under seasonal differences

Path IV was about the relationship between affective feedback and behavioral feedback. In winter, both H61 and H62 were valid, indicating that affective feedback can positively affect both MVPA feedback and LPA feedback, with a greater coefficient of influence on LPA (0.512). For example, architectural spaces with cultural heritage or regional characteristics are more likely to stimulate the preferences and attachment of older adults, thereby promoting the development of group and individual leisure behaviors, while a lively atmosphere will attract more older people to dance or stop to observe. In the test of chain mesomeric effect, it found that there was a path of "perceived environment → affective feedback → MVPA feedback → restorative effect."

As for non-winter, H61 was not established, and affective feedback from older adults people can only positively affect low-intensity behavior. The chain mediation path of "perceived environment → affective feedback → LPA feedback → restorative effect" had been proved. These results all validated the standard learning hierarchy model in attitude theory (63), which states that the attitude (Cognition) of older adults in the park directly affects their feelings or emotions toward the park (Affection), which in turn affects their behavior (Behavior), and then affects the acquisition of restorative effects. The higher the perceived environmental quality of a space, the higher the level of preference and attachment among older adults, the more willing they are to engage in various behaviors in this space, and thus the better the recovery effect of the space on them.

5 Conclusion

On the whole, this study discussed winter and non-winter separately, constructed the "full path" of the restorative effects on older adults' mental health in the parks, and verified the six assumptions and mesomeric effect of its split. The results showed that: (1) both winter and non-winter parks had restorative effects on older adults' mental health, and the overall effect coefficient was slightly higher in non-winter. (2) In winter, H1e and H52 were not be supported, and perceived environment evaluation was not the direct antecedent of restorative effects. Whereas, perceived environment played a role through affective feedback and MVPA feedback, and a chain mediated path of "perceived environment → affective feedback → MVPA feedback → restorative effect" existed. (3) In non-winter, H51 and H61 were not valid, and the restorative effects were achieved through direct and indirect effects. A good perceptual environment can directly and positively affect the acquisition of restorative effects. The indirect paths of "perceived environment → affective feedback → restorative effect," "perceived environment → LPA feedback → restorative effect," and "perceived environment → emotional feedback → LPA feedback → restorative effect" all existed.

Based on the above path decomposition, park optimization can be divided into two approaches: "affective inducing" and "behavior promoting." The "affective inducing" parks should focus on creating its own regional cultural characteristics and a lively atmosphere based on social activity organization. Therefore, in planning and design, on the one hand, attention should be paid to the expression of narrative landscape structure, connecting story lines according to different landscape situations, bringing older adults into a positive "nostalgic" complex (64, 65), and enhancing their sense of identification and dependence on the environment. The "nostalgia" therapy has been proven to awaken local attachment for older adults and can play a role in psychological recovery and healing (66). On the other hand, in terms of detail design, elements with regional characteristics can be appropriately used to stimulate the visual experience of older adults. Landscape sketches with local flavor that can be appropriately added to create a familiar and nostalgic atmosphere in non-winter. Classical landscapes can also be added to enhance their additional value. In winter, the display of ice and snow sculptures and the organization of characteristic activities can enhance the sense of participation of older adults in parks.

The "behavior promoting" parks should differentiate various sports intensities, dividing them into high-energy areas and leisure areas. In winter, the high-energy zone mainly includes path space, water space, instrument space, and square space, while in non-winter, it mainly includes path space, square space, and instrument space. The leisure area mainly involves path space, structure space, and vegetation space. High-energy areas should prioritize the enhancement of convenience and security, while leisure areas should enhance the creation of a sense of interest and belonging. It should be noted separately that the path space, as an important spatial carrier for older adults' sports in the parks, should prioritize the optimization of security factors, and should be zoned for planning and strengthened guidance. For example, in winter, the path space should be cleared of snow as soon as possible, and a plastic dual color track with good elasticity should be selected. Running and walking areas should be divided to prevent mutual interference of different behaviors and improve the safety and comfort of sports. Plants on both sides can add colorful decorations to enhance the fun of the space. In addition, for other functional spaces, in winter, on the premise of timely clearing of snow, the first priority should be to coordinate the size of the space and the adequacy and maintenance of facilities. Semi indoor fitness facilities, item placement facilities, etc. can also be appropriately added to reflect humanistic care in details. Winter themed activities can also be organized with communities, such as ice sculpture and snow sculpture exhibition activities, to enhance spatial attractiveness and participation. In non-winter, the most important thing is to improve the color, form, and layering of plants, and create a pleasant visual, auditory, and odor environment.

Due to the limitations of special climate and special group, the sample acquisition and research results of this study had certain limitations. However, it can still provide a complete exploration logic for related field research and provide certain references for spatial positive intervention at different stages. Future research can be based on this to conduct more in-depth experimental studies, further deepening the different psychological processes of different groups. Thus, intervention design methods corresponding to different psychological processes can be formed.

Data availability statement

The datasets presented in this article are not readily available because due to the nature of this research, participants of this study did not agree for their data to be shared publicly, so supporting data is not available. Requests to access the datasets should be directed to TY, ytjhit@126.com.

Ethics statement

For the studies involving humans because ethical review and approval was not required for the study on human participants in accordance with the local legislation and institutional requirements. The studies were conducted in accordance with the local legislation and institutional requirements. The ethics committee/institutional review board also waived the requirement of written informed consent for participation from the participants or the participants' legal guardians/next of kin because written informed consent from the (patients/participants OR patients/participants legal guardian/next of kin) was not required to participate in this study in accordance with the national legislation and the institutional requirements.

Author contributions

TY: Writing – review & editing, Writing – original draft, Supervision, Software, Methodology, Investigation, Formal analysis, Data curation, Conceptualization. HL: Writing – review & editing, Supervision, Resources, Funding acquisition, Conceptualization. ZY: Writing – review & editing, Investigation, Supervision.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

Publisher's note

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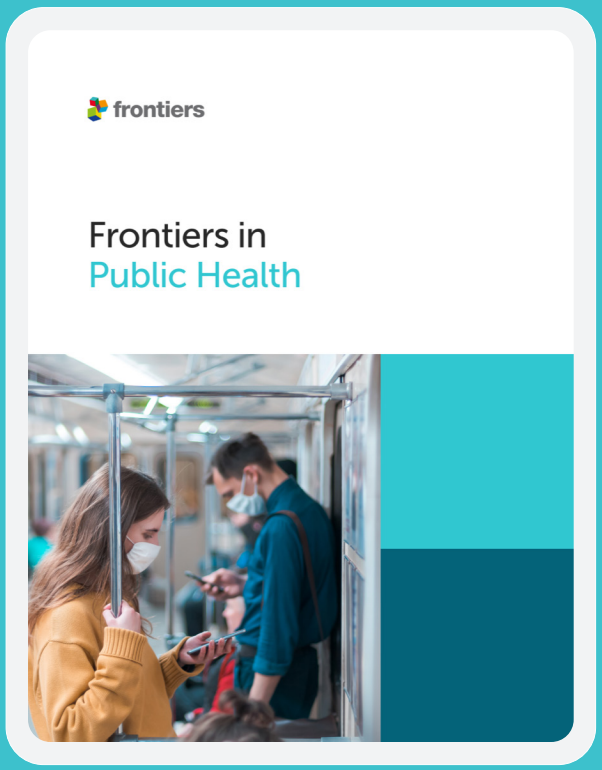

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