Journal of Landscape Research 2026, 18(3-4): 16-18, 26

Evaluation of Urban Park Green Space Layout Based on Equity Principles

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Abstract Currently, the assessment of urban green spaces predominantly depends on macro-level statistical indicators, resulting in issues such as limited evaluation accuracy, disregard for population spatial distribution, and insufficient consideration of the needs of vulnerable groups. Focusing on urban park green spaces as the research subject and residential communities as the smallest evaluation units, this study employs open-source network data and GIS spatial analysis techniques to develop a green space equity evaluation system encompassing three dimensions: quantitative equity, spatial accessibility, and social equity. The study employs the location entropy method to assess the alignment of green space quantity, utilizes the Gaussian two-step floating catchment area method to measure spatial accessibility, and performs a social equity analysis by integrating socioeconomic attributes of communities, including housing prices, floor area ratios, and construction years. This approach facilitates a systematic examination of the issues present in the urban park green space layout. The research findings indicate the prevalence of several urban phenomena, including the uneven distribution of green spaces, marked disparities in resources between newly developed and older urban areas, and significant inequalities in green space accessibility among various social groups. Additionally, optimization strategies have been proposed. This study has enhanced the method for assessing green space equity at a fine spatial scale, thereby offering both theoretical insights and practical foundations for urban green space system planning, the advancement of equalization of green space services, and the promotion of park city development.

Keywords Park green space, Equity, Space layout, Accessibility
DOI 10.16785/j.issn 1943-989x.2026.3-4.004

With the rapid advancement of urbanization in China, the extensive expansion model has led to numerous urban challenges. Under the guidance of ecological civilization principles and the concept of park cities, urban development has transitioned towards quality enhancement. The development of pocket parks and other green spaces has become a crucial strategy for improving the living environment and fulfilling residents' desire to connect with nature. Meanwhile, China's Gini coefficient has consistently exceeded the international warning threshold, highlighting significant issues related to wealth disparity and the uneven distribution of public resources. The contradiction between the population's demand for an improved quality of life and the unbalanced, insufficient development is particularly evident in the domain of park green spaces. China prioritizes the equalization of public infrastructure in its 15th Five-Year Plan and related policies, mandating the equitable provision of green space resources. Currently, domestic park green space planning predominantly depends on traditional macro-level indicators, such as per capita green space area and green space ratio. However, these indicators exhibit limitations, including neglecting variations in location-based services, failing to align with the spatial distribution of populations, and overlooking the needs of vulnerable groups. Consequently, the evaluation system lacks sufficient refinement, which may result in the inequitable allocation of green spaces[1]. With the ongoing advancement of Geographic Information Systems (GIS) and big data technologies, the integration of multi-source real-time data offers robust technical support for small-scale and quantitative investigations into green space equity, thereby addressing the limitations associated with traditional survey data, which tend to be singular and highly subjective. From a policy perspective, Jiangxi Province has issued a series of relevant documents focused on optimizing green spaces, developing pocket parks, and promoting the accessibility and sharing of green spaces. These policies explicitly emphasize the need for a balanced layout of various types of park green spaces, the enhancement of green space service coverage, and the advancement of urban ecological quality. In light of these intersecting factors such as policies, society, technology, and industry status, research on the equity of urban park green space layout holds substantial practical significance.

1 Research objectives and significance

1.1 Research objectives

Currently, domestic research on green spaces seldom engages in specialized discussions from the perspective of residents' walking travel or addresses the differentiated usage demands of park green spaces of varying scales. Due to constraints imposed by geographical location and socioeconomic factors, different population groups experience varying degrees of access to public green space resources. Existing evaluation models that consider differences in facility types, spatial location, and population attributes remain underdeveloped. Drawing on the pluralist theory of equity, this study defines the core concept of equity in park green spaces, identifies key factors influencing green space layout, enhances traditional evaluation methods, and develops a refined, quantitative model for assessing green space equity.

1.2 Research significance

At the scientific level, park green spaces, as components of urban public welfare green infrastructure, often exhibit uneven spatial layout, which can result in inadequate provision of green space services for vulnerable populations, thereby contributing to spatial disparities and social isolation. By employing refined equity assessments to identify deficiencies in green space allocation, disparities in resource access among various social groups can be reduced, mitigating social isolation. Furthermore, open green spaces serve as platforms to foster social interaction, enhance urban inclusivity, and promote the integrated development of diverse cultures. At the practical level, within the context of stock planning, urban construction land and construction funds are limited, leading to a pronounced scarcity of green space resources. This study develops an equity evaluation model to

Received: April 5, 2026 Accepted: May 20, 2026

analyze disparities in public access to green spaces and to identify issues related to their layout. This approach not only enhances the technological system for research on green space equity but also offers a scientific basis for the optimal allocation of urban park green spaces, thereby supporting planning authorities in the efficient and rational utilization of green space resources.

2 Foundation of an evaluation model

2.1 Classification of park green space types

In accordance with the normative standards in the *Classification Standard of Urban Green Space* (CJJ/T 85-2017) and the *Planning Standard of Urban Green Space* (GB/T 51346-2019), this study excludes zoos, amusement parks, and other fee-based specialized parks from its scope, as these are not considered truly public open spaces. Urban park green spaces are categorized into three primary types: comprehensive parks, community parks, and recreational parks. These are further subdivided into seven categories based on area: comprehensive parks of $\geqslant$ 50 hm^2, comprehensive parks of 20–50 hm^2, comprehensive parks of 10–20 hm^2, community parks of 5–10 hm^2, community parks of 1–5 hm^2, community parks of 0.4–1.0 hm^2, and recreational parks of 0.2–0.4 hm^2.

2.2 Selection of residential community as evaluation unit

In research concerning the spatial distribution of public service facilities, the academic community typically employs administrative divisions, such as streets and communities, as fundamental units of analysis due to limitations related to the confidentiality and difficulty of obtaining population data. However, this statistical approach presents notable shortcomings. Firstly, substantial variations in floor area ratio and population density exist among residential communities within the same administrative division, leading to considerable errors when estimating the population served by green spaces. Secondly, the relatively large spatial extent of administrative divisions means that using centroids to define service areas can overlook service gaps, thereby producing overestimated evaluation outcomes. To mitigate the aforementioned issues, the residential community is designated as the smallest unit of evaluation. This approach aligns with the actual living spaces of residents, enables precise calculation of green space service coverage, minimizes data deviations resulting from large-scale zoning, and enhances the validity and accuracy of the evaluation outcomes.

2.3 Acquisition of open-source data from the Internet

Traditional research on green spaces faces limitations including high costs associated with data collection, complex processing procedures, and inadequate spatial accuracy[2]. In contrast, open-source big data available on the Internet offers advantages such as free and convenient access, strong temporal relevance, and enhanced spatial precision, thereby providing an opportunity to optimize technical path in spatial studies of public service facilities. Utilizing an open-source data platform, this study collects three fundamental types of data, including the distribution of residential communities, urban road traffic networks, and the socioeconomic characteristics of human settlements, to support the quantitative analysis of green space equity. This approach aims to ensure that the research findings are objective, detailed, scientifically robust, and reliable.

3 Evaluation of urban park green space equity

3.1 Evaluation of quantitative equity

3.1.1 Influencing factors. The equity of green space quantity is evaluated at both the macro level of the street and the micro level of the community. The rationality of green space layout is assessed based on the degree of spatial balance. Using park green spaces as supply nodes, service radii are delineated in accordance with residents' walking and travel behaviors, and the coverage of residential communities by green spaces is calculated. The primary factors influencing quantitative equity include park classification, geographical location, the number of entrances and exits, and the walking service radius. This study selects walking as the primary mode of travel for residents visiting the park for the following reasons. First, walking is a low-carbon, pollution-free mode of transportation, aligning with the concept of ecological civilization construction. Second, planning standards for community living circles use the walking service radius as the criterion for determining the placement of supporting facilities. Third, walking supports national fitness initiatives and satisfies residents' daily leisure and exercise needs.

3.1.2 Quantitative equity evaluation based on location entropy method. The coverage level of green space services is calculated at both the street and community levels. At the street level, the following formula is adopted: coverage proportion of street green space service=area of residential communities within the service range/total area of residential communities in the street. A coverage rate of 100% represents the ideal scenario, indicating that all residential communities within the jurisdiction have access to green space services. The same calculation method is applied at the community level to assess the green space coverage of individual community buildings.

The study employs the location entropy method to quantify the spatial matching relationship of green space resources at the residential community scale. This approach enables the precise identification of areas exhibiting an imbalance between the supply and demand of green space, thereby providing a foundation for the supplementation and optimization of green space. The formula used to calculate location entropy is presented as follows:

$$LQ_i=(Q_i/D_i)/(Q/D)$$

where LQ_i denotes the location entropy of the i-th residential community; Q_i represents the service coverage area of urban park green space within the i-th residential community; D_i corresponds to the area of the i-th residential community; Q signifies the total service coverage area of urban park green space in the study area; and D indicates the total area of residential communities within the study area.

3.2 Evaluation of spatial accessibility

3.2.1 Influencing factors. Spatial accessibility refers to the ease with which residents can overcome spatial barriers to access park green spaces. It serves as a fundamental indicator for assessing the rationality of green space layout and evaluating the quality of public services. By considering residential communities as the demand side and park green spaces as the supply side, the supply-demand ratio between these two elements is analyzed. Key factors influencing this ratio include the size of the resident population, the urban road network, and the service capacity of the parks. Population size reflects the spatial distribution characteristics of populations and determines the demand for green space. The road traffic network serves as the spatial carrier for residents' travel, with its structure and classification directly influencing traffic efficiency. The quality of park services affects residents' willingness to visit; superior service conditions correspond to increased visitation frequency. This study employs actual service distance as the primary indicator for assessing park supply capacity, thereby simplifying the quantification process while maintaining the scientific rigor of the evaluation.

3.2.2 Spatial equity evaluation based on the improved two-step floating catchment area (2SFCA) method. Scholars have employed various attenuation functions to enhance the 2SFCA method. The traditional 2SFCA method assumes an idealized and uniform distance between the entrance and exit of park green spaces and the centroid of residential communities. However, as the distance between demand points and supply points increases, residents' willingness to visit urban park green spaces correspondingly decreases. Consequently, this method overlooks the analytical errors introduced by distance attenuation. The attenuation properties of the Gaussian function closely align with residents' willingness to visit urban park green spaces in real-world settings. Consequently, this study employs an enhanced 2SFCA method, incorporating the Gaussian function, to assess the spatial accessibility of urban park green spaces. Specifically, the Gaussian 2SFCA method integrates the Gaussian function as its range attenuation component, building upon the traditional 2SFCA approach[3].

3.3 Evaluation of social equity

3.3.1 Influencing factors. Socioeconomic status (SES) serves as a critical indicator for assessing residents' capacity to access public resources. Traditional green space planning frequently allocates resources based on the registered population. Consequently, individuals residing locally with higher economic status are more likely to benefit from high-quality green space resources, whereas access to green spaces in older residential communities and among low-income groups remains limited. In the context of housing site selection, the availability of surrounding green space facilities has become a significant factor influencing residents' purchasing decisions, and green space resources have increasingly emerged as a key marker of disparities in living quality.

Significant differences exist in the demand for green spaces among residents of residential communities with varying attributes. In high-quality communities characterized by low plot ratios, high green coverage rates, and comprehensive internal facilities, the internal greening sufficiently meets residents' daily leisure needs, resulting in a lower propensity to visit external parks. Conversely, in residential communities and shantytowns with high floor area ratios, limited greening, and outdated facilities, there is a deficiency of internal leisure spaces, leading residents to rely more heavily on urban public parks. Five indicators, including resident population, housing prices, construction year, floor area ratio, and green space ratio, are selected based on data accessibility and indicator relevance. These indicators are used to develop a demand evaluation system that quantifies the intensity of green space demand across communities with diverse social and economic levels.

3.3.2 Quantitative equity evaluation based on location entropy method. Utilizing the Gaussian 2SFCA method to acquire accessibility data for green spaces within residential communities, this study superimposes the demand scores of these communities to calculate the supply-demand ratio. Furthermore, the location entropy method is employed to assess social equity, thereby distinguishing the resource matching levels of residential communities characterized by different social attributes.

4 Optimization strategies for urban park green space layout

4.1 Balancing the layout of green space system to achieve inclusive and equitable services

In response to the developmental disparities among urban districts, a differentiated approach to green space renewal and transformation is implemented. The old urban area is characterized by high building density, limited available land for construction, and a scarcity of green space resources. Renovation strategies implemented include hard-site restoration and greening, the removal of illegal constructions to increase green coverage, and the introduction of vegetation wherever feasible. Fragmented and underutilized spaces are identified and transformed into pocket parks and micro-parks to mitigate the shortage of green spaces in these older areas. The new urban area strictly adheres to established green space protection boundaries, proactively reserves land for green infrastructure, and strategically plans green spaces to prevent resource imbalances resulting from subsequent supplementary developments. In urban-rural fringe zones, efforts focus on linking urban green spaces with suburban ecological areas to establish suburban parks and ecological green corridors, thereby promoting the integrated development of urban and rural green spaces[4]. Concurrently, emphasis is placed on the elderly, children, and low-income groups by enhancing supportive facilities such as barrier-free pathways, fitness areas, and children's playgrounds. Additionally, the layout of green spaces around older residential communities, urban villages, schools, and hospitals is optimized to ensure the inclusivity and human-centered design of green space services, thereby mitigating resource disparities among different populations.

4.2 Building ecological green space networks to enhance the ecological functions of cities

In response to the requirements of urban ecological development, it is essential to enhance the diversified ecological service functions of green spaces. To mitigate the urban heat island effect in densely built-up areas, extensive green spaces and waterfront ecological zones should be strategically concentrated, and urban ventilation corridors should be established to regulate the regional microclimate. Incorporating the principles of sponge city construction, hardscape green spaces should be transformed by creating sunken green areas, rain gardens, and artificial wetlands to improve rainwater retention and purification capacities. The plant configuration model should be optimized by selecting native vegetation to develop a composite community comprising trees, shrubs, and grasses, thereby preserving natural habitats and promoting biodiversity. Protective green belts should be established around major traffic arteries and industrial parks to harness the ecological functions of vegetation in noise reduction, dust retention, and air purification. Furthermore, natural features such as mountains, water systems, and ancient or notable trees must be strictly protected, while degraded and polluted idle green spaces should be restored to maintain the stability of the urban ecosystem.

4.3 Activating the existing green space resources to enhance the efficiency of space utilization

The functional integration and enhancement of green spaces are promoted to transcend their solely ornamental role by incorporating functions such as science popularization and education, sports, emergency shelter, and social leisure. Park facilities are improved through the development of fitness trails, sports fields, science exhibition areas, and leisure reading spaces to accommodate the needs of individuals across all age groups. Utilizing waterfront corridors and urban greenways, a linear slow-traffic system is established to connect residential communities, commercial districts, scenic sites, and public service facilities, thereby creating a continuous and unobstructed green transportation network[5]. The integrated development model of "Park+" has been innovated by creating distinctive theme parks that combine commercial, cultural and creative, and leisure industries. This approach activates the vitality of green spaces to ensure the long-term operation and maintenance of the park. Additionally, the transportation

(To be continued in P26)

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connectivity system of green spaces has been optimized by opening previously closed entrances and exits, thereby integrating walking, cycling, and public transportation. These measures reduce residents' access costs to parks and comprehensively enhance the accessibility and utilization efficiency of green spaces[6].

5 Conclusions

Urban park green spaces constitute public welfare infrastructure that optimizes the living environment, enhances ecological structure, and promotes human well-being. In the context of the high-quality development phase of urbanization, the construction of urban green spaces should move away from extensive and fragmented development models. Instead, it should adhere to development principles emphasizing equity and inclusiveness, ecological priority, high efficiency and intensification, as well as systematic coordination[7]. By balancing the layout of green spaces across the region, establishing an interconnected ecological network, revitalizing existing green resources, and enhancing planning and regulatory mechanisms, efforts will focus on advancing the transformation of green space development from mere expansion in scale to improvements in quality, from localized embellishment to comprehensive coverage, and from singular landscapes to diverse and composite environments. It is essential to continuously optimize the structure of green spaces, address deficiencies in green space facilities across both new and old urban areas as well as among diverse social groups, and develop urban green spaces that are ecologically sustainable, inclusive in service provision, and efficient in operation and maintenance. Such efforts will facilitate the construction of park cities, promote harmonious coexistence between humans and nature, and achieve high-quality, coordinated development of urban ecology, society, and public well-being.

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