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Accessibility evaluation of urban basic public service facilities for persons with disabilities: a case study of central Beijing

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Abstract

In urban planning practice, urban basic public service facilities are essential spatial carriers for advancing social fairness and public well-being. Traditional methods of resource allocation that are primarily motivated by supply efficiency are facing new difficulties as China's urban spatial structure shifts from incremental expansion to stock optimization. As fundamental tenets of modern urban planning, equity and justice demand a more inclusive reevaluation of facility allocation, especially with regard to service accessibility and equitable for vulnerable populations. Beijing was chosen as the study region for this investigation, and information on public service facilities for people with disabilities was gathered from 6,080 residential neighborhoods. Accessibility was assessed using an integrated GIS-based analytical framework that combined kernel density analysis, surface-based hotspot detection, network analysis, and inverse distance weighting. This framework was based on the 15-minute living-circle concept and the actual walking speed of people with disabilities. A gap in previous research, which frequently depends on aggregated administrative units and ignores fine-scale spatial inequalities, is filled by the inclusion of surface-based hotspot detection, which enables accurate identification of high-accessibility clusters and peak areas. With high-value clusters concentrated in particular districts and obvious spatial mismatches between facility layouts and anticipated service needs, the results show notable differences in accessibility and facility distribution across service categories. This study suggests methods to increase facility coverage, optimize spatial organization, and improve street-level accessibility in order to overcome unequal facility distribution and insufficient street-network support. The results highlight a change from basic coverage to user-centered service quality and structural adaptability, which supports inclusive urban growth and the sustainable use of land resources.

Key words: critical care, video-assisted training, education distance, e-learning, multimedia.

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Introduction

According to a United Nations report, the global population has reached seven billion, with more than one billion people living with some form of disability, equivalent to onein every seven individuals (United Nations, 2024). Since the 1980s, the definition of "disability" has gradually evolved to emphasise that society often fails to provide adequate support for persons with disabilities or to fully consider their needs (Gleeson, 1997). This lack of inclusive consideration results in restricted mobility and spatial accessibility, leading to the gradual marginalisation of this population. The Convention on the Rights of Persons with Disabilities (CRPD), adopted by the United Nations in 2006, formally defines disability (Qiu *et al.*, 2018) and elevates its understanding to the "social model" of disability (Shakespeare, 1996; Gleeson, 1999), which emphasizes enabling persons with disabilities to participate in society on an equal basis and with autonomy by eliminating widespread barriers to knowledge, information, and the environment. The accessibility of urban public service facilities has long been a significant focus of academic and planning discourse. In Western countries, the study of equity in public service facility distribution, based on accessibility metrics, has grown steadily. Research has addressed various facility types, including urban parks and green spaces (Zhang *et al.*, 2023; Yang *et al.*, 2025), health-carefacilities (Wan *et al.*, 2012), recreational amenities (Cheng *et al.*, 2019), and shopping facilities (Kelobonye *et al.*, 2020). The provision of public services for persons with disabilities has become increasingly important (Groch, 1991) as it directly affects their quality of life in urban settings. Enhancing the accessibility of these facilities also aligns with the World Health Organization's goal of ensuring equal access to effective health services for persons with disabilities (WHO, 2025) and contributes to making public service systems in cities and communities more inclusive and equitable.

To achieve equity, the fundamental requirement is to ensure both the availability and convenience of public service facilities, typically measured through the concept of accessibility. Hansen (1959) first introduced this concept. As the definition has continued to evolve, accessibility has been widely adopted as a quantitative indicator for evaluation of the fairness of public service facility distribution (Jin *et al.*, 2023). Common research methods for assessing accessibility include buffer analysis (Higgs *et al.*,

2012), minimum distance methods (Akpinar, 2016), gravity models (Semenzato *et al.*, 2023), cost-weighted distance approaches (Dou *et al.*, 2016), network analysis (Contreras *et al.*, 2023) and the two-step floating catchment area (2SFCA) method (Wu and Zheng, 2023). As a result, accessibility studies have been extended to various population groups, including – though not limited to – the elderly (Chen *et al.*, 2022), persons with disabilities (Agbelie, 2023), children and family units (Mokomaneand Makoae, 2017). This broader scope accounts for diverse age groups, socioeconomic statuses, and activity needs. A rational allocation of urban public service facilities is therforeessential to improving residents' quality of life and achieving social equity (Song *et al.*, 2024).

China's construction of a barrier-free environment began relatively late. Starting with the Design Code for Urban Roads and Buildings Convenient for Persons with Disabilities (JGJ-50-88) in the 1980s, progressing to the Code for Barrier Free Design (GB50763-2012) in 2012, and most recently, the enactment of the Law of the People's Republic of China on Barrier Free Environment Construction in 2023 (Standing Committee of the National People's Congress of the People's Republic of China, 2023), scholars have begun to explore practical approaches to developing inclusive environments that accommodate the travel needs of persons with disabilities (Liu and Zhao, 1995; Panand Liu, 2007; Sun *et al.*, 2012; Panand Li, 2021). However, compared with industrialized countries in the West, there remains a substantial gap in the utilisation rate of barrier-free support services and facilities in Chinese urban public spaces. Existing surveys reveal that the travel frequency of persons with disabilities is significantly lower than that of non-disabled individuals (Xiang, 2010; Wang *et al.*, 2015), with poor travel accessibility often resulting in "weekly" travel patterns. Among the contributing factors, the urban road network and the distribution of basic public service facilities play critical roles in shaping accessibility for persons with disabilities.

Despite the growing body of research on urban service accessibility, most existing studies focus on the general population and rarely address the spatial equity of public service facilities for persons with disabilities. Furthermore, previous analyses often rely on single-scale or distance-based evaluations, overlooking the interaction between facility distribution, street networks, and the actual mobility constraints faced by disabled groups. To address this gap, this study evaluates the accessibility of basic public service facilities for persons with disabilities in the central urban districts of Beijing, based on the principle of "planning equity." Taking residential communities as origins and key service facilities as destinations, we integrate the two-step floating catchment area (2SFCA) method with network analysis to measure multi-threshold accessibility (5, 10, and 15 minutes) and examine the spatial balance of facility coverage and environmental connectivity. By combining spatial analysis with an equity-oriented perspective, this study provides new methodological insights into accessibility evaluation for disabled populations and offers evidence-based recommendations for urban planning and policy development to enhance inclusiveness, spatial justice, and sustainable urban development (Figure 1).

Materials and Methods

Study area

Considering the wide-ranging and often dispersed spatial distribution of persons with disabilities in urban areas, and in the absence of high-precision individual positioning data, this study assumes that persons with disabilities are present within each residential community. The residential community was therefore set as the demand point, and accessibility to major barrier-free facilities was evaluated based on this basis. The classification of basic public service facilities for persons with disabilities (hereinafter referred to as public service facilities) corresponds to the framework of territorial spatial planning. According to relevant government-issued standards, urban basic public service facilities in cities that are closely related to persons with disabilities include: basic medical and health-care facilities, basic public education facilities, labour and employment service facilities, basic public cultural and sports facilities, and social welfare facilities. According to the draft of the "Tianjin Barrier Free Environment Construction Special Plan (2020-2035)," the municipal public service facility system for persons with disabilities can be divided into four levels and five categories, aligned with the hierarchical structure of territorial spatial planning. The four levels include municipal, district, subdistrict/township and community/village levels, while the five cate-

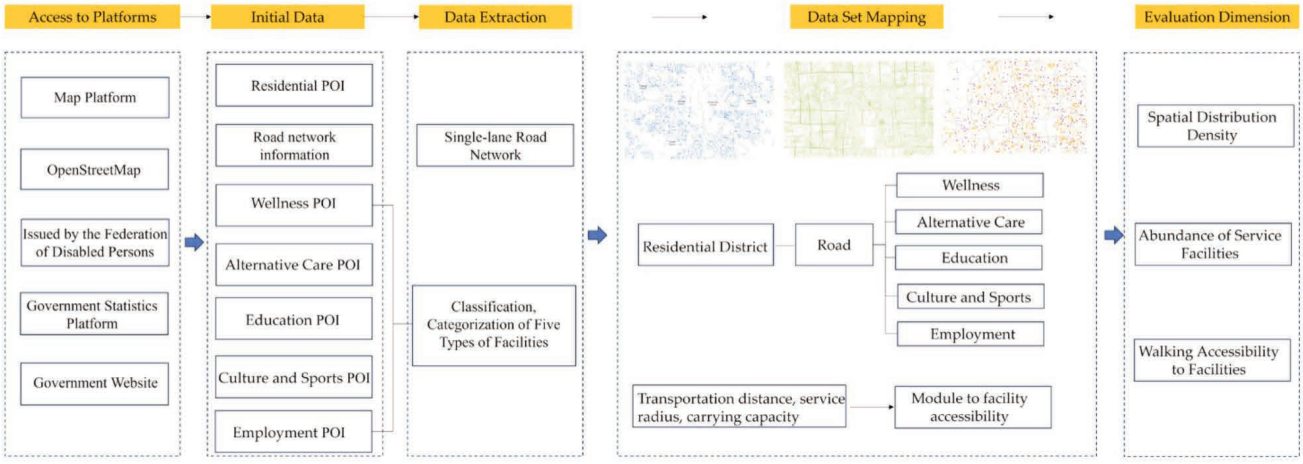

Figure 1. Methodological framework for the evaluation of the accessibility of multiple types of public service facilities.

gories comprised rehabilitation, care, education, employment and culture and sports. In this study, these five categories of facilities were regarded as the destinations for the daily travel of persons with disabilities.

Data collection

As shown in Table 1, this study obtained basic urban data for the year 2024 from the official Beijing Municipal Statistical Bureau website. This dataset includes administrative boundaries, public service facilities and the urban road network,which were sourced from open-access maps and municipal open-data platforms. In this study, residential communities accommodating persons with disabilities were used as the basic spatial unit for analysing the accessibility of urban public service facilities. The spatial data used included the boundary data of Beijing's central city and road network data obtained from OpenStreetMap (OSM). The accessible travel chain for persons with disabilities was modeled from residential areas to public service facilities, with a focus on accessibility during their journeys. Considering the implementation of travel service planning, public service facilities specifically designed for persons with disabilities are selected as key analysis targets. The five core categories – rehabilitation, care, education, employment and culture and sports – were used as the destination types for this accessibility analysis. Using Python, location data of public service facilities were collected by 'crawling' the official website of the Beijing Municipal Government. A total of 6,028 data entries related to service facilities for persons with disabilities, distributed across six administrative districts of Beijing, were initially obtained. After processes including filtering, deduplication, correction and spatial cropping, 5,650 valid data points were retained. These included: 1,016 rehabilitation institutions (including community hospitals), 541 care service institutions for persons with disabilities, 29 special education schools, 370 employment service centres for persons with disabilities, and 3,694 cultural and sports facilities (including cultural and sports halls) for persons with disabilities (Figure 2).

Theoretical construction

Persons with disabilities seek mobility rights equivalent to those of the general population. However, the realization of such rights is strongly dependent on the design and quality of the built environment. Whether persons with disabilities can access basic public services in a rational and normalized manner is primarily reflected in the following three evaluation principles.

Principle of comprehensive spatial coverage and proximity-based service provision

When traveling to basic public services facilities – such as rehabilitation centres, care institutions, employment centres, educational institutions and cultural or sports venues – persons with disabilities typically follow a "shortest-distance-first" travel pattern. Therefore, in evaluating the accessibility of public service facilities, service areas should be established around each facility to ensure comprehensive spatial coverage. Based on this principle, persons with disabilities are expected to to choose the nearest facility within their residential catchment, thereby promoting both efficient resource utilisation and spatial equity in service provision.

Principle of supply-demand matching and balanced allocation

Public service facilities should aim to achieve a dynamic equilibrium between supply and demand. Given their public welfare orientation and the inherent scarcity of public resources, the performance and allocation of such facilities cannot be evaluated solely in terms of economic efficiency (Wei *et al.*, 2020). To realise efficient and equitable provision of basic public services, it is essential to not only meet the fundamental needs of persons with disabilities within service areas but also to scientifically regulate the distribution of resources. This helps prevent both service overload and underutilisation, ensuring fair and reasonable resource allocation across regions.

Principle of regional circulation and stable supply-demand relationships

The public service facility system should establish relatively stable and self-contained supply-demand relationships. Persons with disabilities typically travel from their place of residence to a specific facility and back, forming a barrier-free travel chain of "residence-facility-residence." Such a chain facilitates effective alignment between service supply and demand. However, if supply-demand mismatches occur, certain facilities may become overburdened while others remain underutilised, resulting in resource inefficiencies and diminished service quality. These spatial and functional imbalances can ultimately undermine the overall efficiency, fairness, and resilience of the public service system.

Urban public services accessibility

Density field surface generation method

Density-based point element analysis is a commonly used method for detecting point pattern distributions (Stoyan *et al.*, 2016). Among these, kernel density estimation, which measures first-order spatial effects, is the most widely applied technique (Chen *et al.*, 2016). In this study, the Kernel Density tool from the Spatial Analyst toolbox in the ArcGIS platform is utilized to analyze the spatial distribution of public service facilities. The calculation formula is as follows (Silverman, 1986). The 6,080 residential community points and 5,650 public service facility points within central Beijing were abstracted as point features, and the Kernel Density Estimation (KDE) method in ArcGIS Spatial Analyst employed to visualise their distribution. The construction of the density field was determined by the bandwidth parameter, defined according to the average long-side length of natural urban blocks

Table 1. Data attributes and sources.

Category	Target	Year	Source
Urban statistics	City subway lines and station	2025	Beijing Statistical Yearbook
	Administrative boundaries of the central city	2025	Google Map
	Public service facility points	2025	People's Government of Beijing Municipality
	Space vector data	2025	Gaode Maps API
Geospatial information data	Road network vector data	2025	OpenStreetMap
	Distribution of residential neighborhoods	2025	OpenStreetMap

API, application programming interface.

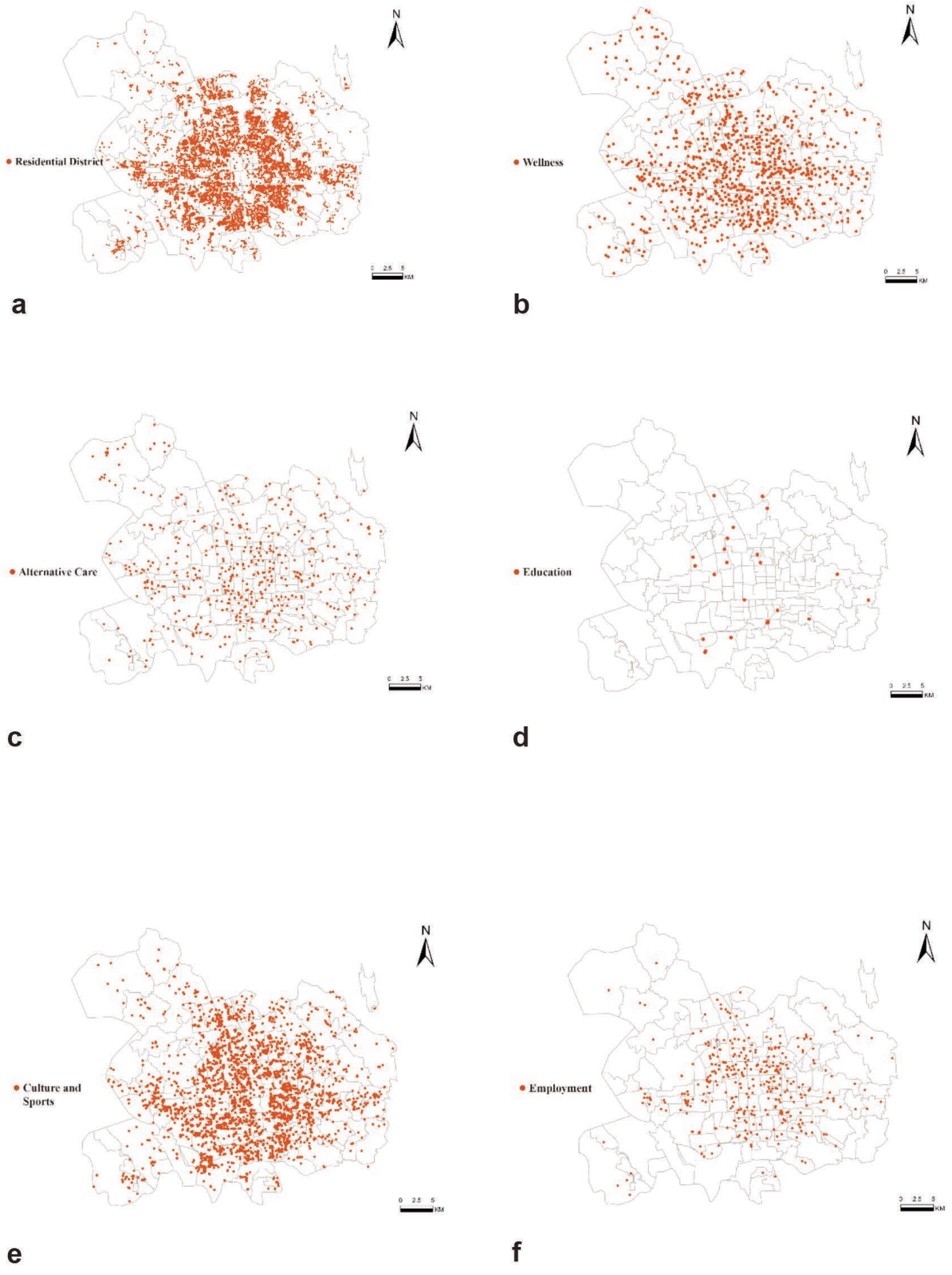

Figure 2. Spatial distribution of residential communities and five types of disability-related public service facilities (wellness, alternative care, education, culture and sports, and employment) in the central urban area of Beijing. **a**) Residential district; **b**) wellness; **c**) alternative care; **d**) education; **e**) culture and sports; **f**) employment.

delineated by the road network. A bandwidth of 20 meters was therefore adopted to generate the density distribution for various facility types, as illustrated in Figure 3.

$$\hat{f}(x,y) = \frac{3}{nr^2\pi}\sum_{i=1}^{n}\left[1 - \frac{(x-x_i)^2 + (y-y_i)^2}{r^2}\right]^2 \quad \text{(Eq.1)}$$

where $\hat{f}$ = etc.(please explain the symbols in te Eq here)

Density-field-based hotspot detector

Hotspot detection based on the density surface was conducted to identify statistically significant clusters of high and low facility densities. The density-field hotspot detector (DF-HD) method was applied to quantify the degree of spatial aggregation and to locate high-value regions of public service facilities. This process highlights areas where facility provision is spatially concentrated or insufficient, enabling subsequent equity-oriented analysis (Zhang *et al.*, 2020).

Accessibility calculation method

Temporal accessibility, also referred to as travel cost, is a key component in road network accessibility analysis. It is commonly evaluated using indicators such as travel distance, travel time, or travel expense. Variations in population size, service capacity, and service quality at different origin-destination points can lead to differences in accessibility outcomes. In addition, the specific travel behaviors of persons with disabilities – including route choice and destination preference – may further affect their actual travel costs.

To assess spatial accessibility for persons with disabilities, this study adopted the two-step Floating Catchment Area (2SFCA) method, which considers both supply-demand relationships and travel impedance within a defined service area. Due to the absence of detailed data on the spatial distribution of persons with disabilities, this study assumes the presence of disabled individuals in each residential neighborhood and assigns equal service demand weights on the demand side.

Using ArcGIS, a road network topology and an Origin–Destination (OD) cost matrix were constructed, with the centroid of each residential community serving as the origin point. Travel time along the network was calculated based on the actual walking speed of persons with disabilities. The resulting accessibility values were interpolated using the Inverse Distance Weighting (IDW) method to generate the spatial distribution of temporal accessibility to disability-related public service facilities in the central districts of Beijing.The calculation formula was the following:

$$A_i^F = \sum_{j\in\{d_{ij}\le d_0\}} R_j \quad \text{(Eq.2)}$$

where A_i^F the accessibility of the disabled location i in the neighbourhood; d_{ij} is the traveling distance or time between the disabled starting location i and the destination; d_0 denotes the catchment threshold (maximum travel time or distance); and R_j represents the supply-to-demand ratio of facility j within its catchment area.

This study employed the traditional 2SFCA model because the primary focus was to identify overall spatial disparities rather than to fit specific distance-decay effects. Moreover, due to the absence of empirical data on the travel behaviour of persons with disabilities, applying weighted decay functions might introduce additional uncertainty. Nonetheless, future research could integrate the E2SFCA or gravity-based approaches to enhance analytical accuracy once detailed travel data become available.

Travel-time thresholds and parameters

The Network Analysis module within the ArcGIS platform was employed to conduct accessibility modeling, using travel time as the impedance factor in the network. Travel time is determined by a combination of road length and traversal speed. According to the experimental study by Boyce *et al.*, the average walking speed of persons with disabilities on level indoor surfaces is approximately 0.8 meters per second (Boyce *et al.*, 1999). Based on the Code for Accessibility Design (GB 50763-2012), the Urban Residential Area Planning and Design Standards (GB 50180-2018), and the "15-minute community life circle" planning concept, three travel-time thresholds – 5, 10, and 15 minutes – were established as the service catchment radii.

Data and implementation

All analyses were conducted using ArcGIS Spatial Analyst and Network Analyst extensions. The network dataset was constructed based on road hierarchy and speed attributes to simulate realistic travel conditions. Residential communities served as demand points, and public service facilities (education, healthcare, culture and welfare centres) were defined as supply points. The results were used to evaluate spatial disparities in accessibility and to identify priority areas for inclusive urban planning (Donald, 1968; Ma and Wang, 2017).

Results

Characteristics of the spatial distribution of public service facilities

Density distribution characterization

Figure 3 presents a digital surfacemodel derivedfrom the spatial distribution of each facility point, reflecting the density characteristics and spatial aggregation patterns of residential communities and various categories of public service facilities for persons with disabilities at the level of spatial aggregation. Overall, if the central urban area is divided into five directional zones – east, west, south, north and center – the spatial distribution shown in the figure indicates a higher density and more clustered pattern of service facilities in the central region, with noticeable spatial zoning differences. The eastern sector, particularly the Sun Rise area, exhibited a more mature and evenly distributed pattern of accessibility across facility types. In contrast, the western sector remained relatively underdeveloped in terms of facility density, with certain categories of public service facilities being partially represented or entirely absent.

Analysis of spatial aggregation characteristics

Through the kernel density analysis, it was found that the five types of facilities generally meet the requirements of urban-level planning and standards (Table 2). For the street and community-level distribution characteristics, this study applies the hotspot detection model for analysis, and the areas with the highest point density of various types of facilities is shown in Figure 4. Analysis shows that rehabilitation institutions and health service centres are most densely distributedin Xicheng District, with clusters located in Exhibition Road Street, Yuetan Street, Taoranting Street. In Chaoyang District, the distribution was found to be more balanced

and adequately supplied, with the highest density values appearing in Tuanjiehu Street, Jinsong Street and Liulitun Street. By contrast, Fengtai District and the western part of Haidian District showed lower densities of recreational and cultural facilities, though some hotspots were found near Xicheng District, particularly in Balizhuang Street and Xiluoyuan Street. However, overall, recreational facilities in Beijing's central urban area were seen as relatively sufficient and evenly distributed.

Nursing service organisations for persons with disabilities were fiund to be most intensively distributed in Xicheng District (Yuetan Street and Desheng Street) and in Dongcheng District (Jingshan Street). In contrast, Guanzhuang and Heizhuanghu areas in Chaoyang District show the lowest density of nursing service facilities, while Xibeiwang Town and Shangdi Street in Haidian District lack sufficient services. The distributions in Fengtai and Shijingshan Districts are comparatively more uniform. The number of special education institutions is relatively limited, with high-density areas mainly concentrated in Xincun Street, Huaxiang Area, and Fangzhuang Area of Fengtai District; followed by Garden Road Street, Zizhuyuan Street, and Shuguang Street in Haidian District. The Olympic Village Street in Chaoyang District belongs to a low-density area, while Shijingshan, together with parts of Haidian and Fengtai, represents the western zones where special education institutions are lacking.

Labour and employment service centres and workshops for persons with disabilities were concentrated around the periphery of Dongcheng and Xicheng Districts, with the densest clusters appearing inGuang'an-men Street, Xinjiekou Street, Jiaodaokou Street, Donghuashijie Street, and Hepingli Street.In Haidian Districtsignificant concentrations are also found in Yongding Road Street, Zizhuyuan Street, and Beixiaguan Street.

Accessibility analysis

Service area construction

Through network analysis, the distribution of the number of accessible public service facilities within a 15-minute walking distance in the six districts of the central urban area of Beijing was calculated (Table 3). ranges. The results indicate that accessibility to sports and recreational facilities have the highest coverage, with 86.8% of residential areas, which means thatpersons with disabilities can walk to nearby sports and recreational facilities within 15 minutes. In contrast, the accessibility to special education institutions is the lowest, with only 3.6% of residential areas are accessible by walking. Access to care and employment facilities reaches around 40%. Therefore, it can be concluded that many residential areas in and around central Beijing lack educational facilities, and nearly 60% sufficient care facilities. Figure 5 illustrates the service coverage of the five categories of public service facilities derived from the network analysis of residential areas.

Walking access to public service facilities

The spatial distribution of travel-time accessibility for various public service facilities for persons with disabilities in the central urban area of Beijing was mapped, as shown in Figure 6. The results indicate that the overall accessibility to public service facilities by walking for persons with disabilities in Beijing'scentral urban area exhibits significant spatial variation. In general, the accessibility pattern demonstrates higher accessibility in the central zones and lower accessibility toward both the eastern and western edges. Accessibility to public facilities correlates strongly with facility density, and multiple high-accessibility zones were identified. These closely overlap with the density clustering pat-

Table 2. Evaluation of public service facilities indicators in central Beijing.

Service (type)	Facility (description)	Municipal level	District level	County/street level	Community/village level
Wellness	Rehabilitation institutions for the disabled	√	√		
	Health service centres (community hospitals)			√	√
Alternative care	Institutions for the care of disabled persons	√	√	×	
	Cozy home for the disabled			√	
	Community daycare			√	
Education	Special education center	√	√		
Culture and sports	Labour and Employment Service center for the disabled	√	√		
	Dream workshop for the disabled			×	
Employment	Arts and sports training and guidance center for the disabled	√			
	Cultural, sports venues/venues	√	√	√	×

Statistics based on the Urban Public Service Facilities Planning Standard GB50442 and the Local Standard for the Construction of Comprehensive Service Facilities for Persons with Disabilities. √indicates that the standard was met at the corresponding administrative level; × indicates that the standard was not met.

Table 3. Accessibility to public service facilities within different walking distance levels for persons with disabilities.

Type of service	5 min		5-10 min		10-15 min		Total	
	n_a	P_a	n_a	P_a	n_a	P_a	n_a	P_a
Wellness	1,742	28.7	1,719	28.3	1,136	18.7	4,597	75.6
Alternative care	678	11.2	884	14.5	1581	26	2,465	40.5
Education	51	0.9	77	1.3	93	1.5	221	3.6
Culture and sports	790	13.0	815	13.4	804	13.2	2,409	39.6
Employment	2,982	49.0	1533	25.2	760	12.5	5,275	86.8

n_1 represents the number of residential areas with accessible public service facilities for persons with disabilities; P_a represents the percentage proportion of n_1 toof the total number of residential areas = 6,080.

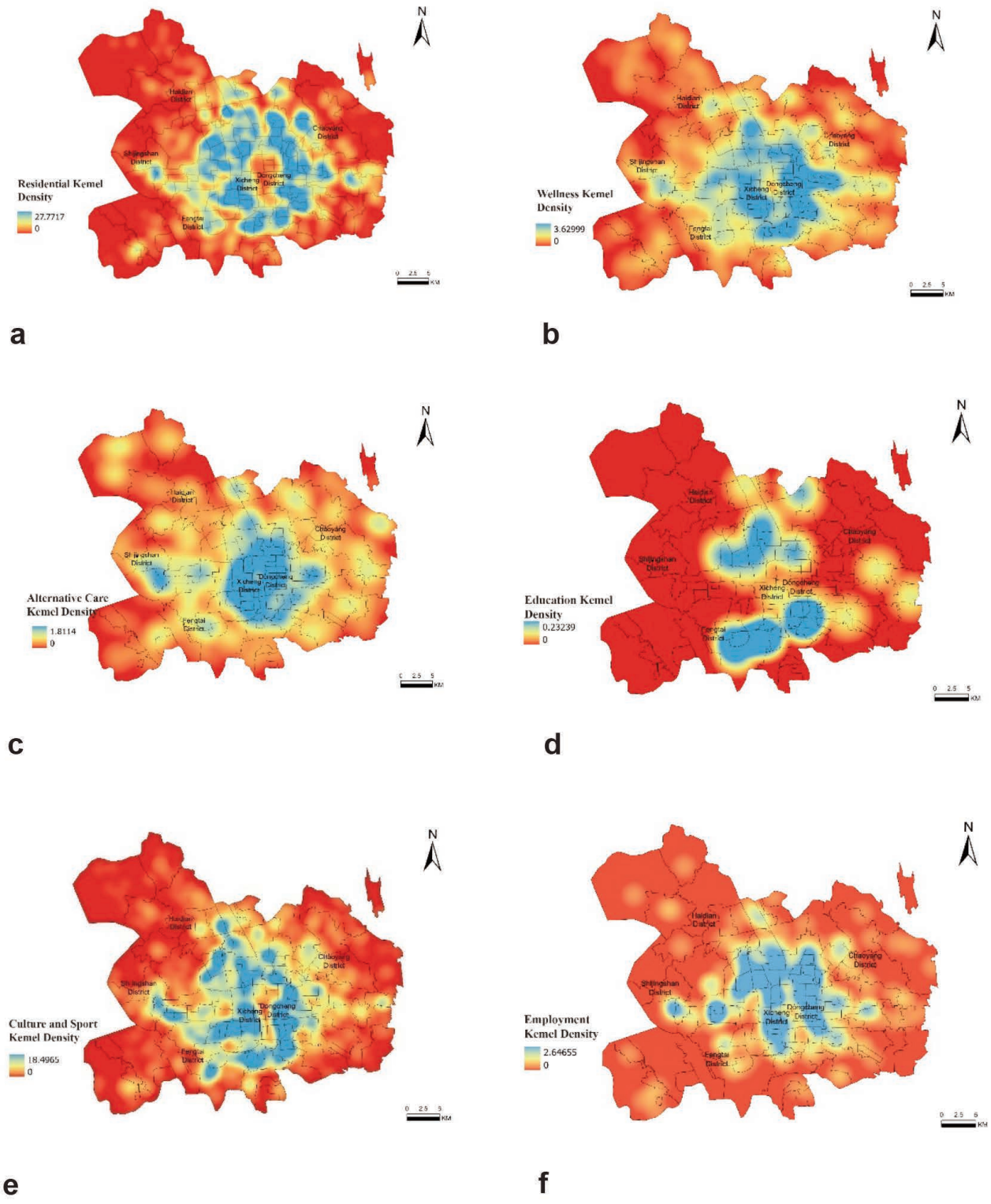

Figure 3. Kernel density analysis. **a**) Residential district; **b**) wellness; **c**) alternative care; **d**) education; **e**) culture and sports; **f**) employment.

terns discussed earlier. The highest accessibility levels are concentrated in the core streets of each district and in several towns in the northern and southern sectors of the study area.

From the perspective of various types of facilities, accessibility generally declines from the central areas toward the periphery, but this decline is neither continuous nor linear. In some central neighbourhoods, accessibility drops sharply resulting in areas where the level of accessibility is significantly lower than that from adjacent streets, forming localised "accessibility depressions." This phenomenon is particularly evident in Dongcheng and Xicheng Districts, although the extent and location of these depressions vary among different categories of public service facilities. Recreational facilities show a pronounced central clustering pattern, with high-accessibility zones concentrated in the core areas.

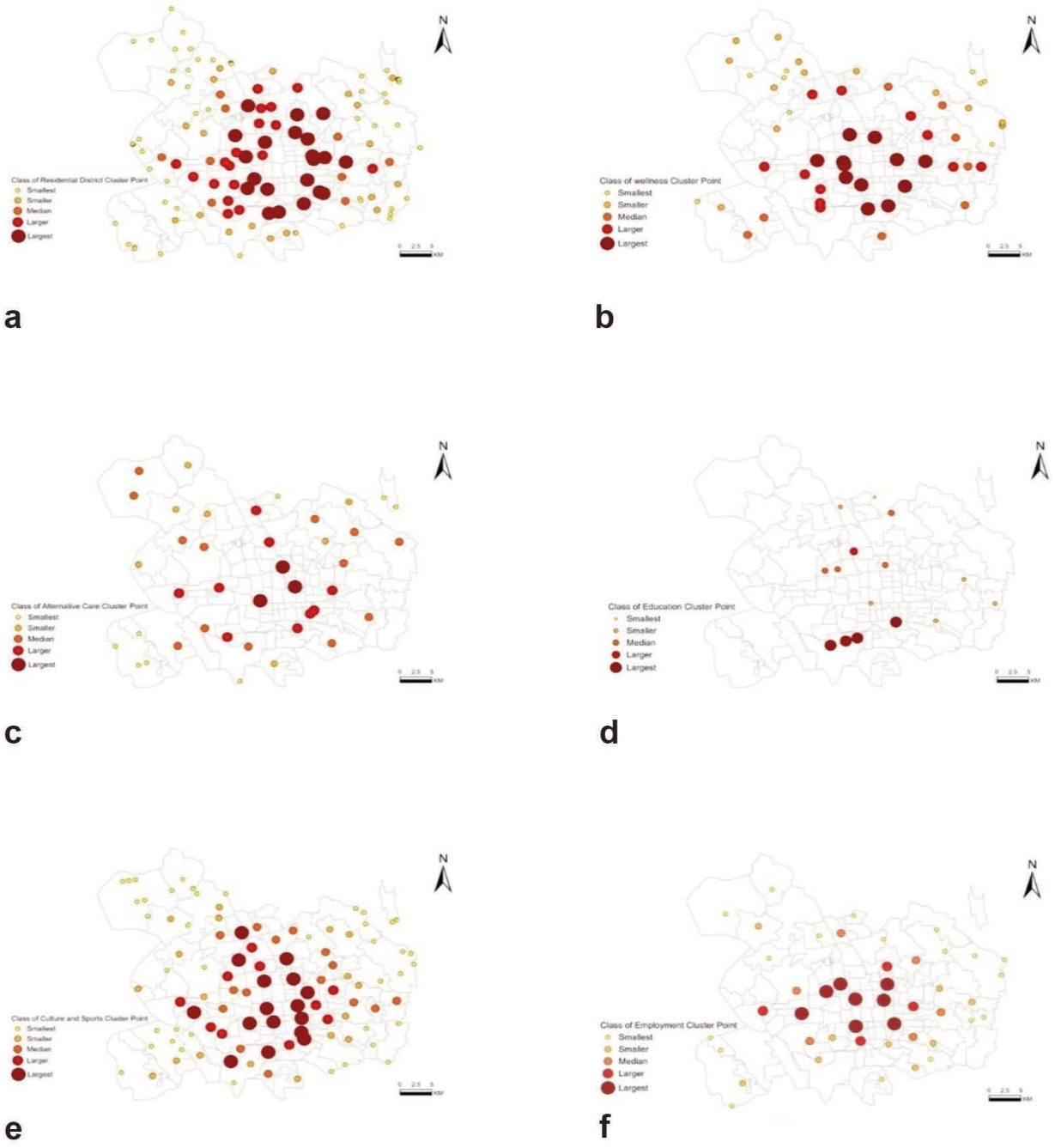

Figure 4. Density-field based hotpot detector. **a**) Residential district; **b**) wellness; **c**) alternative care; **d**) education; **e**) culture and sports; **f**) employment.

Neighbourhoods near the suburban fringes of Haidian, Chaoyang and Fengtai Districts display lower accessibility values, while notable accessibility depressions appear in the Shichahai, Qianmen, and Jingshan Street areas. Care facilities exhibit smoother transitions between accessibility levels, showing a clearer diffusion trend from the centre toward surrounding zones. Their main low-accessibility pockets are located in Shichahai Street and Tianqiao Street. Educational facilities show a highly uneven accessibility distribution, with better accessibility in Xicheng and Haidian Districts, but lower values in Dongcheng, Chaoyang, Shijingshan and Fengtai. The lowest accessibility scores were found in Pingfang and Dongba in Chaoyang and in Huaxiang in Fengtai. The primary accessibility depressions were fiund to be concentrated around Desheng Street, Shichahai Street, and

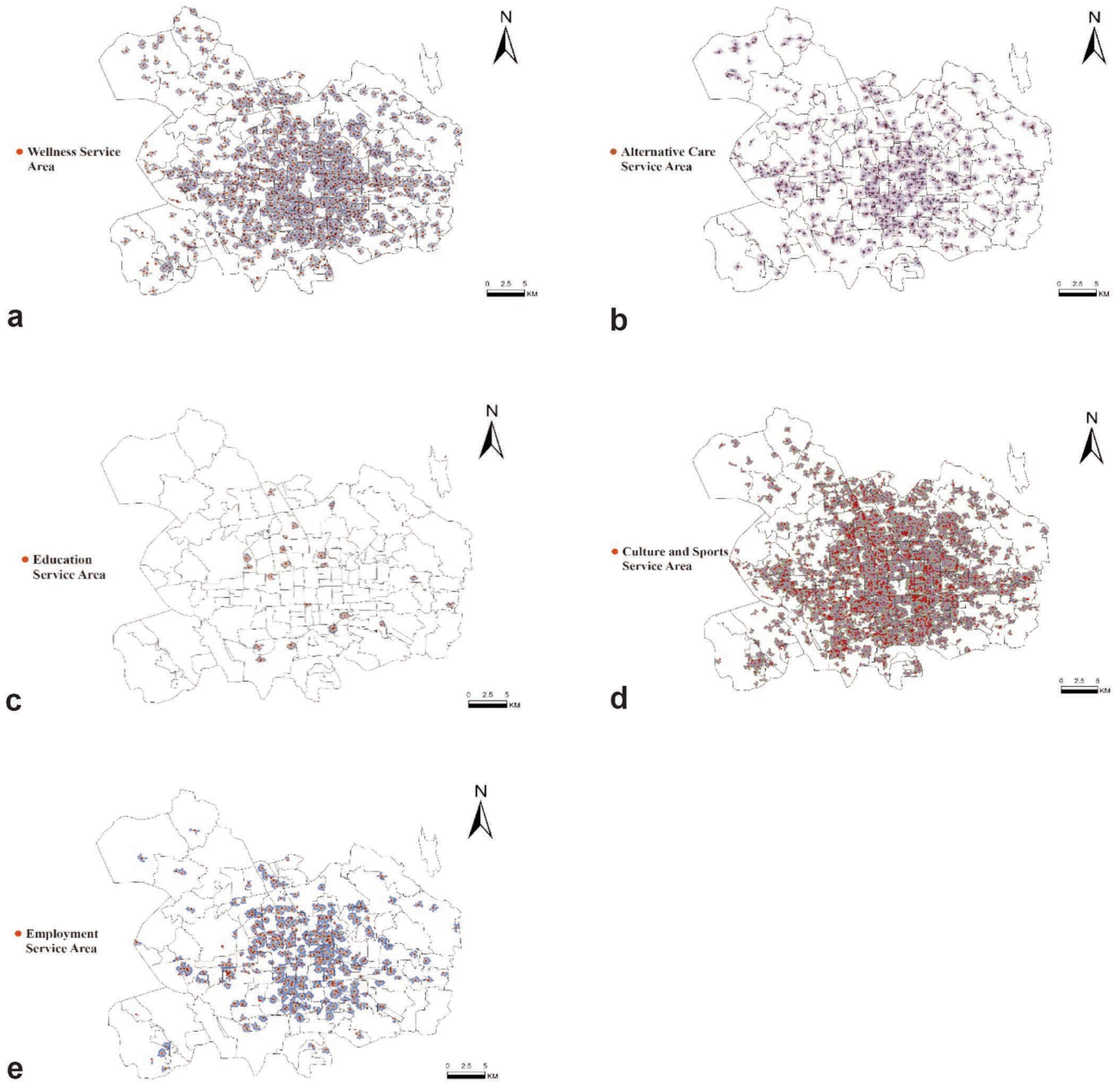

Figure 5. Public service facilities service area analysis. **a**) Wellness; **b**) alternative care; **c**) education; **d**) culture and sports; **e**) employment.

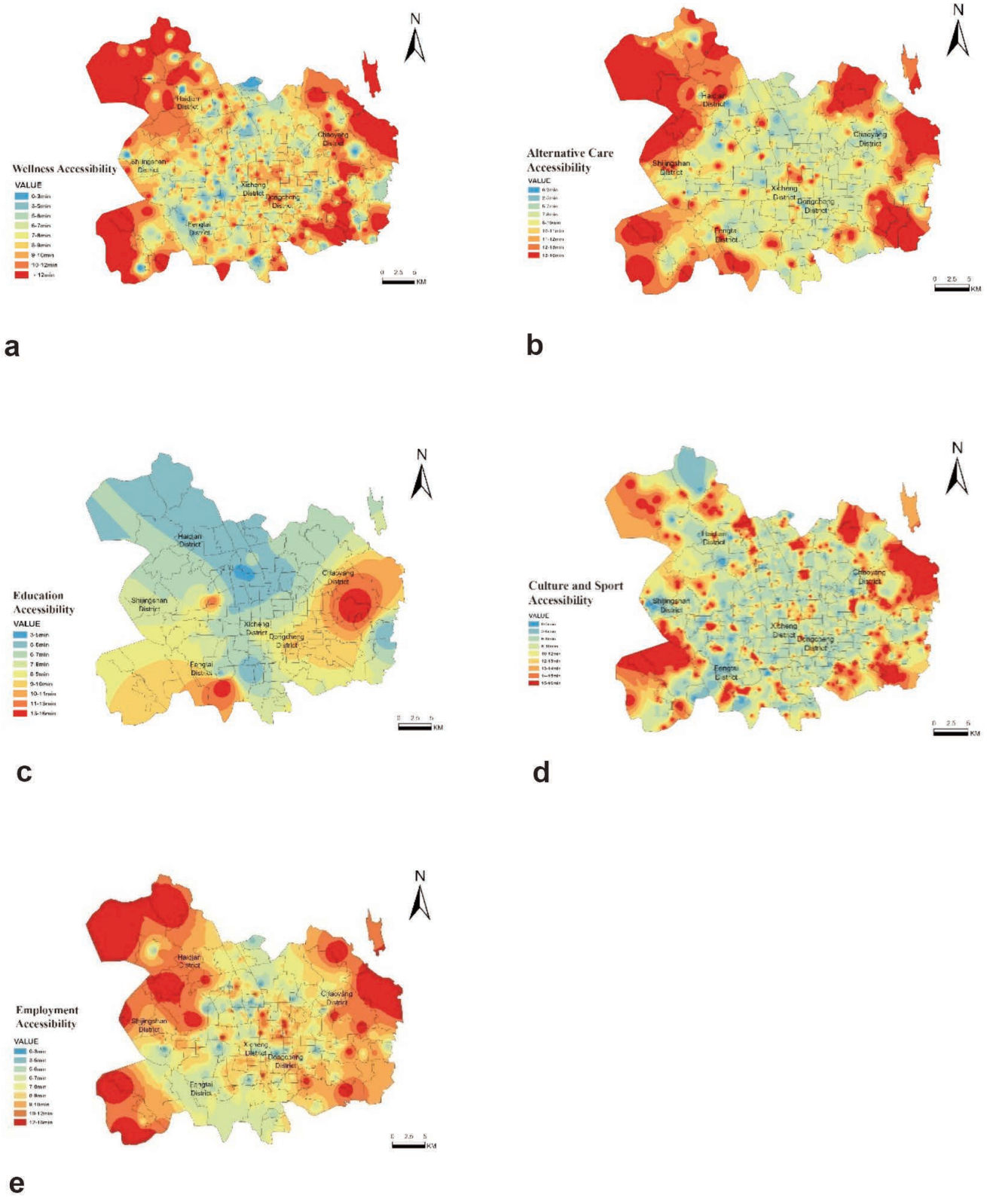

Figure 6. Public service facilities accessibility analysis. **a**) Wellness; **b**) alternative care; **c**) edu-cation; **d**) culture and sports; **e**) employment.

Beixinqiao Street. Cultural and sports facilities demonstrate the smallest area requiring over 15-minute walking distance, indicating the highest overall accessibility among all categories. This kind of low-accessibility pockets are mainly distributed in Shichahai Street, Jiaodaokou Street and Qianmen Street.

Discussion

This study demonstrates that the supply and spatial distribution of disability-related public service facilities in the central districts of Beijing present a complex pattern. Facility density and road network density are both significantly negatively correlated with minimum travel time (r=-0.249), indicating that in areas where facilities and road resources are more concentrated, persons with disabilities can access daily services more conveniently, reflecting higher levels of accessibility. In contrast, the correlation between the number of service types and minimum travel time is relatively weak (r=-0.067), suggesting that service diversity, while beneficial, is not yet a decisive factor under the current spatial configuration. Overall, the accessibility of public service facilities for persons with disabilities is mainly influenced by three spatial factors: facility coverage, facility distribution density, and road network density.

Facility coverage is the most direct factor influencing accessibility. Areas such as Shichahai have repeatedly been identified as "accessibility depressions," indicating persistent service gaps even within the urban core. Limited access to facilities tends to exacerbate the vulnerability of disabled populations (Qiu *et al.*, 2023). Efforts should focus on increasing the coverage of disability-related facilities – particularly rehabilitation, care, and employment centres in low-accessibility zones – as a direct means of improving spatial equity. This aligns with the Barrier-Free Environment Construction Law (2023) and the "15-Minute Community Life Circle" planning framework, both of which emphasize proximity-based service provision. At the same time, these spatial disparities exhibit strong path dependency, reflecting a long-standing bias in resource allocation toward land value and economic efficiency rather than social need. To correct such inequities, planners must not only "fill the gaps" spatially but also adjust institutional criteria that govern how and where resources are distributed.

The spatial layout of facilities exhibits a clear "patchy" clustering pattern, and such structural imbalance is itself a major source of accessibility inequality (Liu *et al.*, 2023). The findings indicate that high facility density alone does not guarantee high accessibility – if surrounding road networks and service hierarchies are poorly coordinated, the potential benefits of clustering are diminished. In some areas, functionally homogeneous facilities lead to high quantity but poor structural balance. Therefore, it is necessary to reorganize the spatial relationships among facilities of different functions across the community, sub-district, and city levels to enhance both the precision and effectiveness of facility allocation.

Road network density determines the effective service radius of facilities. High connectivity can partially compensate for low facility density, while low connectivity amplifies travel costs. Route choices for persons with disabilities are highly dependent on pavement quality, continuity, and perceived safety (Alharbi *et al.*, 2024). Improving pedestrian connectivity – through continuous sidewalks, curb ramps, tactile paving, adequate lighting, and safe crossings – can expand the effective service areas of existing facilities and enhance both perceived safety and accessibility for disabled users.

In summary, facility density and road network connectivity are the dominant determinants of accessibility, while service diversity plays a secondary role. A holistic approach integrating facilities, networks, and environments should be adopted, positioning accessibility for persons with disabilities as a core indicator of spatial justice within the coordinated decision-making of urban planning, transport, housing, and civil affairs sectors. Methodologically, this study applies a 2SFCA framework that integrates multi-type facilities, network-based travel times, and spatial structural characteristics – revealing the structural mechanisms of spatial inequality more systematically than conventional analyses focusing on single facility types or general populations.

As a foundational component of urban planning practices – such as community transport systems, living circle planning, and the spatial layout of public service facilities – accessibility evaluation plays a critical role in promoting the development of a more human-centered and inclusive urban spatial environment. Anchored in a "people-oriented" perspective and with a particular focus on persons with disabilities, this study introduced an intuitive, dataaccessible, and operationally practical framework to evaluate the spatial accessibility of urban public service facilities. The objective was to offer strategic guidance and scientific evidence for promoting equitable allocation and inclusive facility planning in urban settings.

An analytical framework that integrates both service area coverage and facility density evaluation is proposedIn this way macroscale urban spatial structures with microscale spatial differences at the street and community levels can be linked. This multiscalar approach aligns with the contemporary transformation in spatial planning, which emphasizes equity and human-centered service provision. The framework facilitates horizontal comparisons between cities and facility types and supports spatial planning strategies that couple macro-level regional coordination with micro-level implementation. Such an approach contributes to the establishment of a national-territorial spatial planning system under the policy directive of "multi-plan integration."

Limitations

However, some limitations remain. The data do not distinguish between different types of disabilities or mobility behaviors, and the model does not include distance decay or subjective perception variables. Future research could incorporate the E2SFCA model, mobility trajectories, and perception-based surveys to explore the interaction between physical accessibility and social inclusion, providing an empirical foundation for building cities that are equitable, accessible, and inclusive.

Conclusions

This study bridges methodological innovation with practical relevance: it not only refines the accessibility evaluation framework but also transforms analytical results into actionable guidance for equitable spatial planning and policy formulation. Through the application of digital urban management technologies, this study emphasizes the importance of linking theoretical evaluation methods with continuously evolving technical tools. The integration of big data platforms and GIS technologies enables comprehensive and dynamic monitoring of accessibility to public service facilities for persons with disabilities. Future studies should incorporate finer-grained population data, service provision capacity, and real-time usage metrics to enhance the systematization,

precision, and responsiveness of accessibility evaluation frameworks – ultimately contributing to the development of intelligent, differentiated, and people-oriented public facility layouts. The findings presented hold clear implications for advancing equitable urban development and disability-inclusive planning. The spatial disparities identified in facility density and network accessibility provide an evidence base for prioritizing investment in underserved neighborhoods. By quantifying accessibility inequalities, the research supports planners and policymakers in developing differentiated strategies that address both spatial and institutional imbalances – linking urban renewal, land-use regulation, and social service delivery. Moreover, integrating accessibility metrics into routine spatial governance can enhance cross-sectoral collaboration among planning, transport, and civil affairs departments, ensuring that the goal of "fair, accessible, and inclusive" urban environments is realised in practice.

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