A Study on the Spatial Accessibility and Equity of Healthcare Facilities in Beijing

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Abstract. This study examines Beijing as its research area, employing the Enhanced Two-Step Travel Search Approach (E2SFCA) to systematically evaluate the spatial distribution patterns, accessibility characteristics, and equity levels of healthcare facilities from both driving and public transport perspectives. Results indicate that high-quality healthcare resources in Beijing are significantly concentrated in the central urban districts, with insufficient resources in the distant suburbs and ecological conservation zones. Healthcare accessibility exhibits a pronounced "core-periphery" decreasing concentric structure, with disparities being more pronounced when using public transport. Equity analysis indicates severe disparities in healthcare resource distribution, with substantial gaps between central urban areas and suburbs. Regions with high ageing populations generally face low accessibility, creating a dual vulnerability pattern of "high age – low resources". Through quantitative spatial accessibility and equity assessments, this study reveals key contradictions and spatial disparities in healthcare resource allocation within megacities, providing scientific reference for promoting rational resource distribution and enhancing urban public service standards.

Keywords: Accessibility; Equity; Medical facilities; E2SFCA

1 Introduction

Health equity constitutes a vital component of social justice, with spatial accessibility and equitable distribution of healthcare resources serving as pivotal indicators for assessing public health standards [1,2]. As a megacity, Beijing confronts dual pressures from rapid urbanization and profound population ageing. Despite possessing relatively abundant healthcare resources overall, the city exhibits profound spatial imbalances in its distribution. The central urban districts exhibit high population concentration, accompanied by outward migration and a rising proportion of elderly residents, leading to sustained growth in healthcare demand. Consequently, the potential risks to social equity are becoming increasingly apparent.

Regarding research methodologies, early studies predominantly relied on simplistic indicators such as population-to-bed ratios. In recent years, scholars have increasingly adopted more sophisticated spatial interaction models, particularly the Two-Step Travel Search Approach (2SFCA) and its refined iteration (E2SFCA), which more accurately

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reflect residents' opportunities to access healthcare resources [3,4]. For equity assessments, tools such as Lorenz curves, Gini coefficients, and disparity indices are widely employed [5,6]. Nevertheless, existing research exhibits several shortcomings. Firstly, most analyses remain confined to the district level, lacking finer-grained spatial examinations at the sub-district or township level. Secondly, equity evaluations predominantly focus on accessibility outcomes themselves, with insufficient exploration of disparities among distinct groups, such as the elderly or between urban and rural residents.

This study aims to conduct a systematic analysis of the spatial distribution and equity of healthcare resources in Beijing by integrating the Enhanced Two-Step Travel Search Approach (E2SFCA) with a multidimensional equity assessment. The research will not only examine the overall spatial pattern but also explore disparities across different regions and among various population groups, thereby providing scientific evidence for optimizing healthcare resource allocation and formulating urban public health policies.

2 Data and Method

2.1 Study Area

Beijing, China's capital and megacity, serves as a multifaceted hub encompassing political, economic, cultural, and technological functions. The municipality comprises 16 districts spanning approximately 16,400 square kilometers. Its spatial structure exhibits, with the central urban core transitioning successively to the city's sub-centers and a concentric pattern of distant suburban new towns. The central urban area concentrates substantial high-quality public service resources, exhibits high population density, and features a concentrated distribution of healthcare facilities. Peripheral areas, predominantly comprising ecological conservation zones and emerging residential districts, have a higher proportion of elderly residents within their population structure but suffer from relatively inadequate healthcare resources. This spatial characteristic of "high concentration in the core and relative scarcity in the periphery" makes Beijing a typical case study for examining the spatial accessibility of healthcare resources and social equity. Simultaneously, against the dual backdrop of rapid urbanization and deepening ageing, Beijing faces both the pressure of continuously growing demand for healthcare services and the strategic mission at the national level of balancing public services. Consequently, the research findings hold significant reference value for other megacities.

2.2 Data Sources

Data for this study were primarily integrated from multiple sources. Healthcare facility data, obtained through open mapping platforms, encompassed hospital locations, classification tiers, and bed capacities to characterize the spatial supply pattern of medical services. Population data, derived from official censuses and statistical records, reflected demographic distribution and ageing characteristics across subdistricts and townships. Transport network data encompassed urban roads, public transport routes, and metro information, enabling simulation of accessibility variations across different

travel modes. Additionally, administrative boundary data comprised vector files delineating subdistrict and township borders, providing the foundational spatial framework for analysis. The integrated utilization of these multi-source datasets facilitated the detailed characterization of healthcare resource supply-demand relationships at a granular scale, offering robust data support for subsequent accessibility modelling and equity assessments.

2.3 Methods

Accessibility Calculation. This study employs the Enhanced Two-Step Floating Catchment Area (E2SFCA) method to measure the spatial accessibility of healthcare facilities in Beijing. Building upon the traditional Two-Step Floating Catchment Area (2SFCA) model, this approach incorporates a distance decay function to more accurately capture residents' potential access to healthcare resources. Its fundamental methodology comprises two steps: First, centered on healthcare facilities, the demand population within a defined service radius (set at 30 minutes by car and 60 minutes by public transport in this study) is counted, and the intensity of healthcare resource supply per capita is calculated [7,8]. Second, centered on residents' dwelling points, the supply situation of all healthcare facilities within their accessible range is aggregated and weighted by distance decay coefficients to derive an accessibility index for residents' access to healthcare resources.

Compared to simple accessibility metrics, E2SFCA comprehensively considers factors such as healthcare supply scale, population demand density, and transport impedance. It not only reflects the quantitative distribution of resources but also captures the impact of different transport modes on residents' access to medical care. Consequently, this method is particularly suited for analyzing the spatial equilibrium of healthcare resources in megacities.

Fairness Evaluation. Regarding fairness evaluation, this study employs a multi-dimensional indicator approach to systematically characterize the equitable distribution of healthcare resources in Beijing. Firstly, the Gini coefficient measures the overall fairness of healthcare resource distribution, with its value intuitively reflecting resource concentration or dispersion across spatial units [9]. Secondly, the disparity index compares accessibility differences between distinct groups, focusing primarily on disparities between central urban and suburban residents, as well as between the elderly population and the general population. This reveals potential disadvantages faced by socially vulnerable groups in accessing healthcare resources. Finally, the Lorenz curve serves as a visualization tool to intuitively display the uneven distribution of healthcare resources across different spatial units or population groups, aiding in the identification of key high-risk areas [10].

By integrating and Lorenz curve, the rationality of healthcare resource allocation in Beijing can be comprehensively assessed across three dimensions: overall equity, group

disparities, and visual representation. This approach not only illuminates structural inequalities within the "center-periphery" framework but also provides targeted quantitative evidence for subsequent public policy formulation.

3 Results

3.1 Spatial Distribution of Medical Facilities

Medical resources in Beijing exhibit a highly centralized distribution pattern. Premium resources, such as Grade III Class A hospitals, are predominantly concentrated within the six urban districts, particularly in Dongcheng and Xicheng districts, where the majority of beds and medical service capacity are located. This clustering phenomenon is evident not only in the distribution of high-grade hospitals but also in the spatial patterns of specialist hospitals and general hospitals. In stark contrast, ecological conservation zones and outlying new towns possess limited medical facilities, predominantly comprising primary healthcare institutions. These serve as an excessively large catchment area, rendering them inadequate for meeting the daily healthcare needs of the population. Spatial statistical analysis indicates that the density of medical facilities in the six urban districts averages over ten times that of suburban areas.

3.2 Accessibility Pattern

Based on the E2SFCA model calculations, Beijing's healthcare accessibility exhibits a concentric pattern centered on the urban core, with accessibility decreasing progressively towards the periphery (see Fig.1). The most pronounced radial pattern radiates from the Forbidden City as its geometric center. Accessibility indices for streets within the central urban districts significantly exceed those in suburban areas, with disparities between certain streets reaching tens or even hundreds of times. This disparity is more pronounced for public transport modes. Outer districts exhibit markedly lower accessibility indices due to insufficient route density and frequent transfers, whereas the six urban districts demonstrate superior public transport accessibility owing to dense rail networks.

Further comparison across transport modes reveals that while driving accessibility in peripheral areas slightly outperforms public transport, it still lags significantly behind the central urban core. The concentric differentiation becomes more pronounced under public transport modes, reinforcing the service divide between the city center and suburbs.

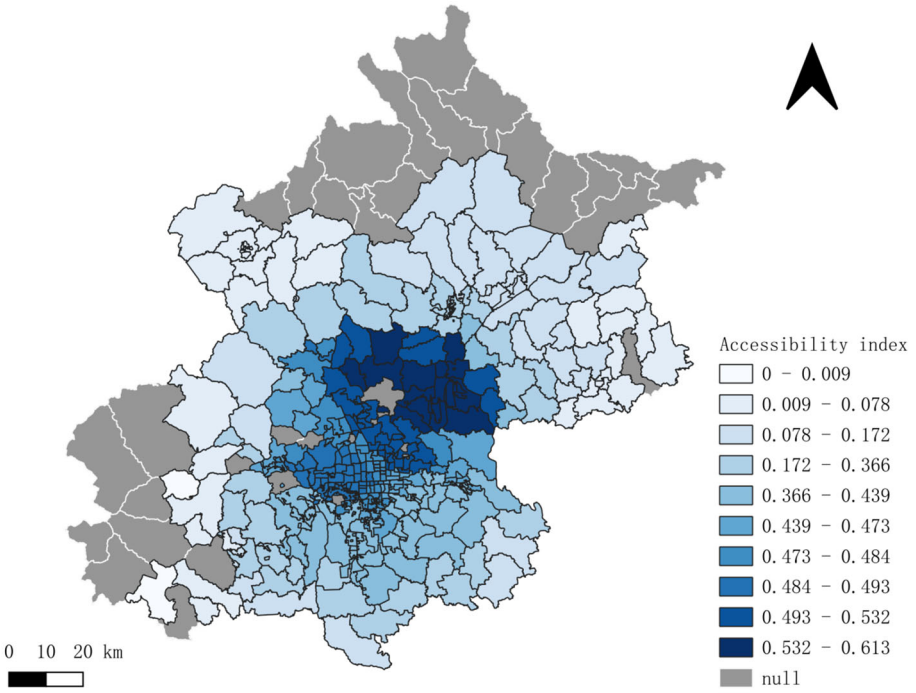

Fig. 1. Spatial Accessibility Distribution of Healthcare Resources in Beijing Based on E2SFCA.

3.3 Fairness Assessment

The fairness assessment indicates significant inequality in the overall distribution of healthcare resources across Beijing. The Gini coefficient falls within the "highly unequal" range, signifying excessive concentration of healthcare service opportunities in a minority of areas. The median healthcare accessibility in central urban subdistricts is approximately 15 times that of suburban areas, reflecting a substantial disparity that is more pronounced when measured by public transport accessibility. Differential index analysis further reveals a structural accessibility divide between central and peripheral districts. At the population group level, elderly residents in peripheral areas consistently exhibit healthcare accessibility indices below the overall population average, exposing a dual vulnerability pattern of "advanced age coupled with scarce resources." This configuration implies heightened risks for elderly populations in peripheral suburbs regarding healthcare access opportunities.

4 Discussion

The findings of this study align closely with relevant research on other megacities globally, consistently identifying significant disparities in healthcare resource distribution

between core urban districts and peripheral areas. Taking cities such as Shanghai, Tokyo, and New York as examples, high-quality medical facilities are typically highly concentrated in central zones, while peripheral regions grapple with inadequate healthcare provision. However, as the national capital, Beijing exhibits a more pronounced concentration of healthcare resources and greater disparities in accessibility gradients. This not only highlights the primacy effect but also reflects the tension between the city's functional positioning and population distribution.

This finding holds significant implications for Beijing's future healthcare resource allocation and public service optimization. Firstly, the spatial configuration of healthcare facilities should align with polycentric, cluster-based urban development strategies. This entails increasing the construction and deployment of medical facilities in urban sub-centers, new towns, and large residential areas to alleviate pressure from excessive concentration in the core districts. Secondly, enhancing the coverage and operational efficiency of public transport can effectively reduce travel times for residents in outlying areas, mitigating accessibility disparities caused by transport constraints. Concurrently, efforts should be made to decentralize high-quality healthcare resources. This can be achieved through establishing branch hospitals, implementing management cooperation agreements, and establishing medical personnel exchange mechanisms to enhance healthcare service capabilities in suburban areas. Building upon this foundation, further strengthening the development of community health service centers is essential to consolidate the primary healthcare network and establish a multi-tiered, tiered diagnosis and treatment service system. Additionally, for residents in remote areas, exploring measures such as transport subsidies or dedicated public transport routes to support their access to healthcare can help ensure equitable healthcare opportunities.

It should be noted that this study retains certain limitations in its data and methodology. Firstly, population data represents static statistical outcomes, failing to account for diurnal population movements and future trends, which may underestimate actual demand in certain areas. Secondly, while the E2SFCA model effectively simulates spatial accessibility, it does not fully account for individual variations in healthcare choices and behaviors. Future research could integrate mobile phone signaling data, movement trajectory data, and questionnaire surveys to more precisely characterize healthcare mobility patterns and population demand characteristics, thereby enhancing the dynamism and practicality of analysis.

Overall, enhancing the accessibility and equity of healthcare resources is not merely a matter of spatial optimization but fundamentally concerns social justice and public welfare, representing a crucial direction for modernizing governance in megacities. The findings of this study provide valuable experience and reference for healthcare resource allocation in Beijing and other megacities, while also offering data support and theoretical foundations for subsequent public policy formulation and urban health governance.

5 Conclusion

This paper employs the E2SFCA model and equity indicators to evaluate the spatial distribution, accessibility, and equity of healthcare facilities in Beijing. Findings reveal that high-quality healthcare resources are highly concentrated in central urban districts, while distant suburbs and ecological conservation zones exhibit widespread shortages. Healthcare accessibility follows a diminishing "core-periphery" pattern, with public transport disparities being particularly pronounced. Equity analysis reveals severe disparities in healthcare distribution, particularly pronounced in ageing suburban areas, creating a dual vulnerability of "high age – low resources".

Policy implications suggest Beijing should integrate healthcare resource allocation with its multi-center, cluster-based development strategy. This entails enhancing medical facilities in sub-centers and new towns, while mitigating accessibility disparities through transport optimization, decentralization of premium resources, and community healthcare system development. It should be noted that this study excluded dynamic population data and healthcare-seeking behavior; future research incorporating mobile signals and questionnaire surveys could enhance precision. Overall, enhancing healthcare accessibility and equity is not merely a spatial optimization issue but a critical aspect of megacity governance and improving public welfare.

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