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Analysis of the Spatial Distribution of Primary Education Resources in Beijing's Chaoyang District from a Supply-Demand Perspective

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Abstract: *This study aims to reveal the spatial distribution pattern of primary school educational resources in Beijing's Chaoyang District and their alignment with school-age population demand, assess the equilibrium level of regional educational resource allocation, and provide scientific basis for optimizing educational facility layout. Based on multi-source data including elementary school facility locations, demographic statistics, and urban road networks, this study integrates kernel density analysis, buffer zone analysis, Gaussian two-step search function (Ga2SFCA), and bivariate local spatial autocorrelation to construct a quantitative evaluation framework for spatial accessibility and supply-demand matching of educational facilities. Results indicate: (1) Spatial accessibility to primary education resources in Chaoyang District exhibits significant spatial heterogeneity, improving overall with increasing distance thresholds (2km, 3km, 4km in this study); (2) Accessibility patterns show superior conditions in western, southern, and parts of northern areas, gradually declining toward northern and eastern peripheral zones;(3) Supply-demand imbalances (identified through local spatial autocorrelation) are concentrated in parts of the northern and southern areas, reflecting spatial mismatches between resource allocation and population distribution; (4) Overall equilibrium requires improvement, with pronounced disparities between core and peripheral zones. These findings clarify the weak areas and spatial imbalances in primary school resource allocation within Chaoyang District, providing direct reference for optimizing facility layout and promoting educational equity.*

Keywords: *Elementary school, Accessibility, Gaussian two-step mobile search method, Supply-demand perspective*

1. Introduction

The spatial equity of urban basic education resources directly impacts educational fairness and social justice. As a starting point of compulsory education, the distribution pattern of primary school resources not only affects children's access to schooling but also closely relates to regional population structure, urban development planning, and social equity. As one of the core urban districts of the capital, Beijing's Chaoyang District has actively expanded educational resource supply in recent years through measures such as the construction of school consortiums and the establishment, renovation and expansion of schools. However, existing evaluation systems primarily focus on quantitative indicators, with insufficient quantitative analysis of the rationality of spatial layout and the degree of supply-demand matching.

In Chaoyang District's practical implementation, GIS-based spatial analysis techniques have been extensively applied to optimize the layout of primary education resources. For instance, Lu Tianqi (2015) evaluated the accessibility of primary education resources in Chaoyang's central urban area, identifying uneven resource distribution within the study zone and proposing recommendations for optimizing resource allocation [1].Zhang Xinting et al. (2023) employed an improved Gaussian two-step moving search method in their study of Suzhou High-Tech Zone, revealing imbalanced educational resource distribution and optimizing accessibility through new facility site selection [2].Cao Zhixing et al. (2025) applied a two-step moving search method to analyze kindergarten accessibility in Beijing's Haidian District, identifying uneven resource distribution within the study area [3]. These studies demonstrate that Gaussian functions effectively reflect residents' convenience in accessing educational services during accessibility analysis, particularly for educational facility layout research in urban core areas [4].

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Taking Beijing's Chaoyang District as a case study, this research employs 400m×400m population grids as the basic analytical unit to systematically evaluate the spatial configuration characteristics of primary school educational resources. First, buffer zone analysis was used to calculate the service coverage range of primary schools. Subsequently, based on the OD cost matrix and the Gaussian Two-Step Mobile Search Approach (Ga2SFCA), the spatial accessibility between population grids and primary schools was quantified at different travel distance thresholds. Finally, supply-demand matching analysis revealed the spatial coupling relationship between educational resource distribution and population density.

2. Study Area and Data Sources

2.1. Study Area

Chaoyang District is located in the eastern and northeastern parts of Beijing's urban core, spanning geographical coordinates 39°48'–40°09' N and 116°21'–116°42' E. As Beijing's largest district by area and population, it covers 470.8 square kilometers, administers 24 subdistricts and 19 townships, and hosts approximately 3.446 million permanent residents—representing 15.8% of Beijing's total population. As a typical transitional area between urban and rural zones, Chaoyang District faces challenges in educational development due to population density and diverse demands. According to statistics from the Chaoyang District Education Commission, the district has 68 primary schools. According to the Chaoyang District 2024 National Economic and Social Development Statistical Bulletin, the district had 174,309 primary school students enrolled in 2024, representing 5.05% of its total population. This indicates that Chaoyang has achieved a certain scale and coverage capacity in basic education. However, due to high population density and uneven distribution of educational resources, issues of educational equity necessitate further optimization of resource allocation. Population density distribution in Chaoyang District is shown in Figure 1.

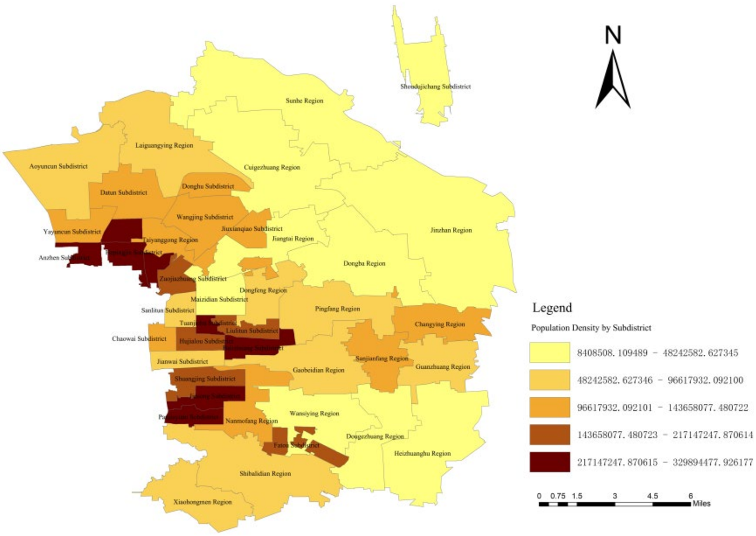

Figure 1: Population Density Distribution in the Study Area.

2.2. Data Sources

Population data for this study was obtained from the WorldPop website, specifically the 100m resolution total population raster data (2020). As this data represents a projection of China's 2020 population, discrepancies exist with actual population figures. Therefore, the raster data was adjusted using the Seventh National Population Census data for Beijing's Chaoyang District, refined to the subdistrict level as shown in Figure 2:

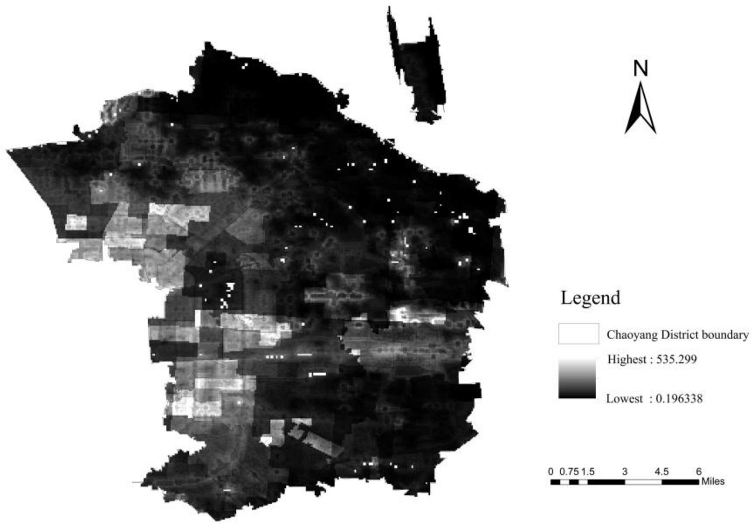

Figure 2: Corrected Population Data.

Primary school data includes school information, teacher counts, and geographic coordinates. School data is sourced from Beijing Local Treasure and respective school websites. Geographic coordinates are obtained from AutoNavi and converted to WGS84 coordinates via the Topography Home website. Projection transformations are applied to the primary school point data, the road network data, and the administrative boundaries of Chaoyang District. Topological checks are performed on the road network data, and a new network dataset is created. The processed road network is shown in Figure 3.

Figure 3: Road Network.

2.3. Research Methods

2.3.1. Kernel Density Analysis

Kernel density analysis is a GIS spatial analysis method that provides a continuous spatial representation of discrete data to visually depict its distribution pattern [5].

This study employs kernel density analysis to examine the spatial distribution patterns of primary school educational resources in Beijing's Chaoyang District. By quantifying the concentration levels and spatial distribution patterns of primary school facilities within the area, it preliminarily reveals the spatial differentiation characteristics of educational resources in the study region. This provides foundational spatial analysis support for subsequent evaluations of the balanced layout of primary schools in Chaoyang

ISSN 2616-5783 Vol.9, Issue 2: 1-10, DOI: 10.25236/AJHSS.2026.090201

District.

2.3.2. Buffer Analysis Method

A spatial buffer zone represents the influence or service range of a geographic entity. Buffer zone analysis automatically generates polygons within a specified width around spatial point, line, or area features [6]. This study employs the buffer analysis tool in ArcGIS spatial analysis, using POI point data of primary schools within the area as core elements to establish a fixed-radius service range model.By setting service radius thresholds, this method analyzes the accessibility of basic educational resources for different residential areas within the defined radius. This approach provides a preliminary assessment of the spatial coverage efficiency and service blind spots of educational facilities within the region, without considering other influencing factors such as transportation networks or population distribution. It serves as the foundational spatial analysis basis for this study.

2.3.3. Gaussian Two-Step Mobile Search Approach

The distance decay function within the search radius of the Gaussian 2SFCA exhibits an "S"-shaped decay pattern. This improves upon the original two-step mobile search's binary approach—where accessibility within the search radius was assumed uniform—by adopting a continuous decay function[7].Following relevant literature , this study selects teacher count as the supply indicator for primary education facilities[8]. An origin-destination (OD) cost matrix is employed to account for the impact of the actual road network on accessibility. The specific calculation process comprises two steps:

Step1: Calculate the supply-demand ratio Rjfor each elementary school. Based on the OD cost matrix, compute the actual travel distance d(ij) from each school j to all fishing points i, selecting only fishing points where dij≤ d0. We apply a Gaussian function to estimate the demand of the school-age population and then calculate the corresponding supply-demand ratio.

$$R_j = \frac{S_j}{\sum_{i \in \{d_{ij} \le d_0\}} G\left(d_{ij}, d_0\right) D_i}$$

Where Sjrepresents the supply capacity of elementary school j (in this study, the number of teachers[8]); dijis the travel distance from fishing village i to elementary school j (calculated via the OD cost matrix); d0is the maximum acceptable service distance; Diis the school-age population of fishing village i.

The formula for G(dij, d0) is:

$$G\left(d_{ij}, d_0\right) = \begin{cases} \dfrac{e^{-\frac{1}{2}\left(\frac{d_{ij}}{d_0}\right)^2} - e^{-\frac{1}{2}}}{1 - e^{-\frac{1}{2}}}, & d_{ij} \le d_0 \\ 0, & d_{ij} > d_0 \end{cases}$$

Step 2: Calculate the educational accessibility index Aifor each fishing village. The travel distance dij from fishing village i to elementary school j is computed on the basis of the OD cost matrix. Filter schools where dij≤ d0. Weight and aggregate the supply-demand ratios Rjof each school using Gaussian decay to obtain the accessibility index Ai.A higher Aivalue indicates more abundant primary school educational resources and better accessibility for that residential area.

$$A_i = \sum_{i \in \{d_{ij} \le d_0\}} G\left(d_{ij}, d_0\right) R_j$$

2.3.4. Bivariate Local Spatial Autocorrelation

Bivariate Local Spatial Autocorrelation (Bivariate LISA) clustering maps divide study areas into four categories by testing the significance of local spatial associations between supply and demand variables: HH (High-High): High supply corresponds to high demand, indicating resource allocation aligns with demand. LL (Low-Low): Low supply meets low demand, indicating inherently limited demand for such resources or services in the area, thus avoiding excessive resource investment. HL (High-Low): Supply levels significantly exceed demand, potentially leading to resource waste, increased costs, or inefficient services. LH (Low-High): Low supply meets high demand, creating “supply shortages” that often become key targets for policy intervention, requiring either increased supply or optimized demand-side management [9].

This study primarily employs bivariate local spatial autocorrelation analysis on the ArcGIS platform

ISSN 2616-5783 Vol.9, Issue 2: 1-10, DOI: 10.25236/AJHSS.2026.090201

to examine relationships between different data categories. When investigating the relationship between primary education accessibility and population density, the required variables were exported from ArcGIS in shp format and imported into GeoDa for bivariate local spatial autocorrelation analysis[10].

3. Results Analysis

3.1. Spatial Distribution of Primary Schools in Chaoyang District

3.1.1. Kernel Density Analysis

Kernel density analysis was employed to assess the clustering intensity of elementary school locations in Chaoyang District, as illustrated in Figure 4. It is evident that the distribution of primary schools in Chaoyang District is uneven. Schools are primarily concentrated in the well-developed, densely populated CBD area, forming clusters centered around urban districts such as Sanlitun Subdistrict, Tuanjiehu Subdistrict, and Chaowai Subdistrict. Additional clusters emerge at the junctions of Liulitun Subdistrict, Balizhuang Subdistrict, and Pingfang Town, while multiple focal points are observed at the boundaries of Changying Town and Sanjianfang Town.In urban-rural fringe areas like Jinzhan Town, Laiguangying Town, and Olympic Village Subdistrict, the distribution of primary schools is sparse due to lower population density.

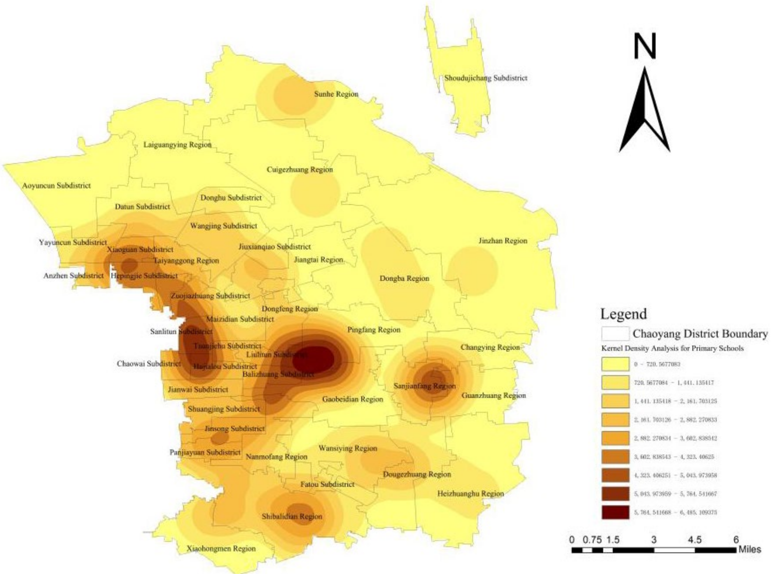

Figure 4: Primary School Kernel Density Analysis.

3.1.2. Service Radius Analysis

This study utilized buffer zone analysis to determine the service coverage of primary schools in Chaoyang District, as illustrated in Figure 5. It is evident that primary schools within Chaoyang District cannot fully cover all fishing points within a certain radius, indicating that the allocation of elementary school educational resources in Chaoyang District exhibits certain issues of irrationality and mismatch. The core area in western Chaoyang District is largely covered within the buffer zones, suggesting a relatively reasonable layout of primary schools in these regions. The closer to the outer ring road, the greater the uncovered areas, indicating that students in some peripheral areas must travel farther to attend school. This is primarily due to lower population density and fewer educational resources in these regions.

ISSN 2616-5783 Vol.9, Issue 2: 1-10, DOI: 10.25236/AJHSS.2026.090201

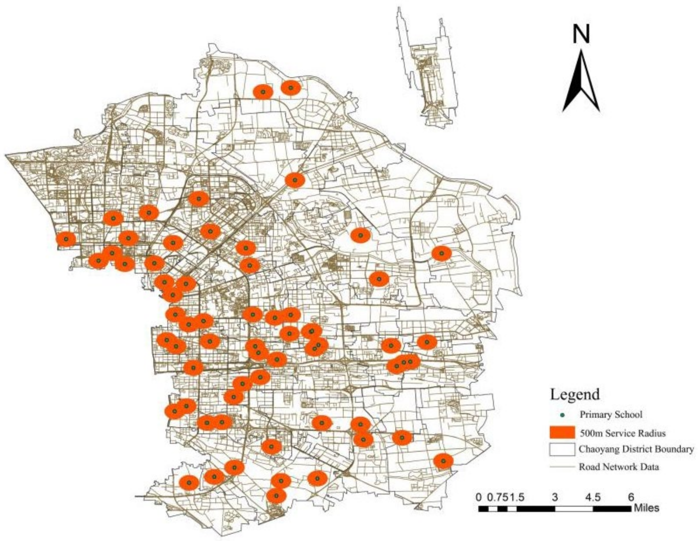

Figure 5:500m and 1000m Service Radius Buffer Zone Analysis.

3.2. Spatial Layout Analysis of Primary Schools

3.2.1. Accessibility Analysis Based on Different Service Radii

According to the State Education Commission's "Several Opinions on Formulating Standards for Compulsory Education Facilities, Implementation Steps, and Planning Statistical Indicators," the distance between a student's residence and school should generally be within 3 kilometers. This study analyzes the accessibility of primary education resources within three service ranges: 2000m, 3000m, and 4000m.

When the maximum service radius is set at 2000m, as shown in Figure 6, out of 3140 study units, 60 are invalid, leaving 3080 valid units. Among these, 1352 units match, meaning 1352 fishing points are accessible. Classifying accessibility into five levels—high, relatively high, moderate, relatively low, and low—revealed: 17 grids (0.54%) with high accessibility; 21 grids (0.67%) with relatively high accessibility; 77 grids (2.45%) with moderate accessibility; 421 grids (13.41%) with relatively low accessibility;816 grids had low accessibility, accounting for approximately 25.99%.

When the maximum service radius is 3000m, as shown in Figure 7, out of 3140 study units, 60 invalid units were excluded, leaving 3080 valid units. Among these, 1947 units matched, meaning 1947 fishing points were accessible. Classifying accessibility into five levels—high, relatively high, moderate, relatively low, and low—reveals: 18 grids with high accessibility (approximately 0.57%); 43 grids with relatively high accessibility (approximately 1.37%); 125 grids with moderate accessibility (approximately 4.00%); and 658 grids with relatively low accessibility (approximately 21.06%);1,103 grids had low accessibility, accounting for approximately 35.13%.

At a maximum service radius of 4000m, as shown in Figure 8, 3080 valid study units remain after excluding 60 invalid units from the total 3140. Among these, 2375 units matched, indicating 1947 fishing points possess accessibility. Classifying accessibility into five levels—high, relatively high, moderate, relatively low, and low—revealed: 48 grids with high accessibility (approximately 1.66%); 43 grids with relatively high accessibility (approximately 1.40%); 266 grids with moderate accessibility (approximately 8.64%); and 1,098 grids with relatively low accessibility (approximately 35.65%);920 grids had low accessibility, accounting for approximately 29.87%.

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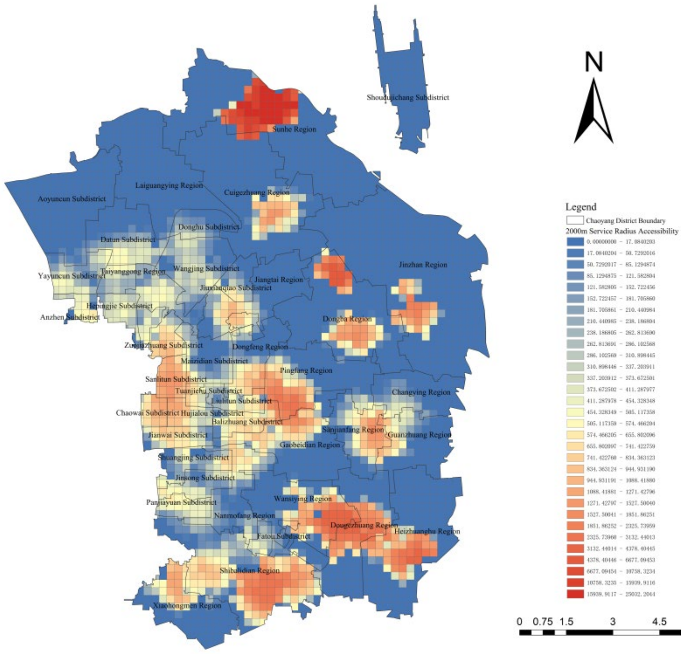

Figure 6:2000m Accessibility Analysis.

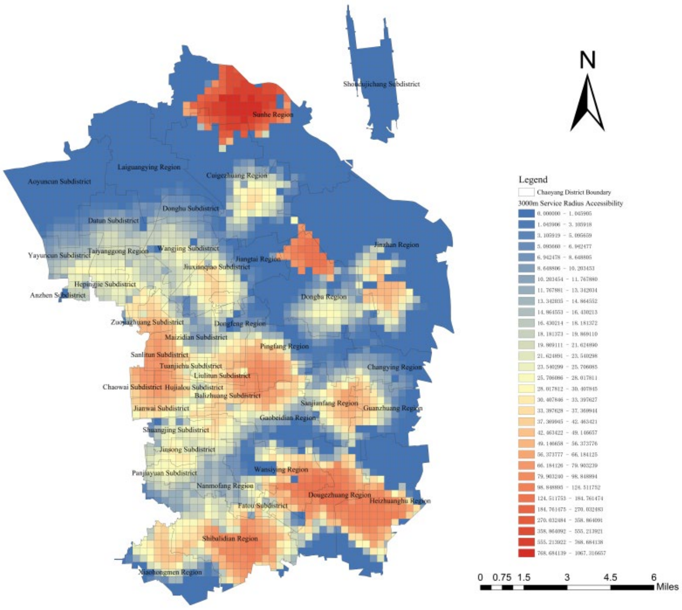

Figure 7:3000m Accessibility Analysis.

ISSN 2616-5783 Vol.9, Issue 2: 1-10, DOI: 10.25236/AJHSS.2026.090201

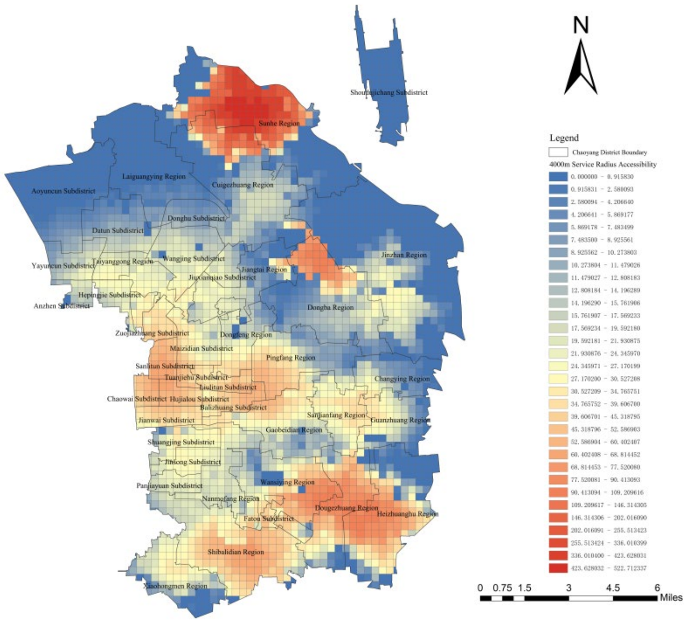

Figure 8:4000m Accessibility Analysis.

3.3. Supply-Demand Matching Analysis

Based on the preceding analysis, accessibility to primary education resources generally improves with increasing distance thresholds. Therefore, we will conduct a supply-demand matching study for accessibility and population density within a 4000m service radius. As shown in Figure 9, high-supply/high-demand areas are primarily concentrated in the core districts of Sanlitun Subdistrict, Hujialou Subdistrict, Tuanjiehu Subdistrict, Jianwai Subdistrict, Liulitun Subdistrict, and Hujialou Subdistrict.Low-supply/low-demand areas are primarily located in urban-rural fringe zones, including parts of Sunhe Town, Capital Airport Subdistrict, Jinzhan Town, and sections of Heizhuanghu. Low-supply/high-demand areas are concentrated in northern districts like Wangjing Subdistrict and Xiaoguan Subdistrict. Despite adequate primary education resources, these areas experience insufficient supply due to high population density.High supply-low demand areas are primarily concentrated in parts of Sunhe Town, Heizhuanghu Town, and Dougezhuang Town. These areas have low population density but concentrated educational resources, resulting in oversupply. Supply-demand imbalances exist in these regions.

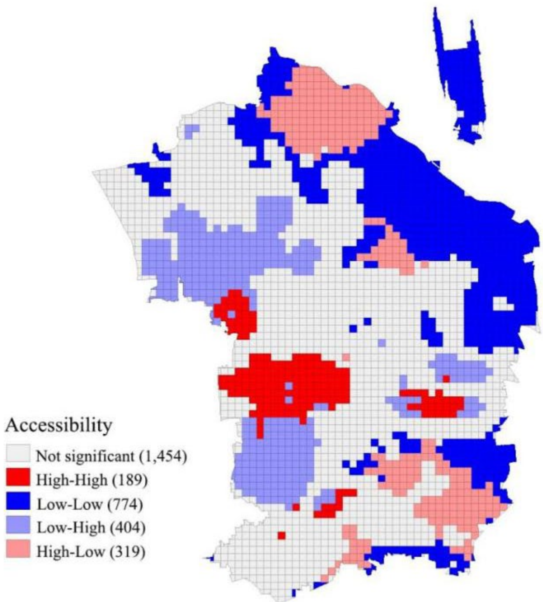

Figure 9: Dual-Variable Cluster Analysis of 4000m Accessibility and Population Density.

4. Conclusions

This study examines the accessibility of primary school facilities within different service radii in Beijing's Chaoyang District, analyzing the supply-demand relationship between accessibility and population density. Using GIS spatial analysis and the two-step Gaussian search method, this study comprehensively evaluated the spatial distribution of primary education facilities in Chaoyang District. Kernel density analysis and buffer zone analysis provided an initial understanding of the spatial distribution of primary schools in Chaoyang District. Findings indicate that primary education resources are primarily concentrated in the densely populated CBD core area and surrounding regions, while students in other township areas lack access to nearby schools. To ensure local enrollment for students in the study area, the following recommendations are proposed based on the research findings:

First, optimize regional educational resource allocation. To address the shortage of educational resources in northern and eastern townships, it is recommended to reasonably increase primary school facilities in areas like Jinzhan Town, which have lower population density but larger territorial coverage. By scientifically calculating the distribution of school-age populations and educational demand, new schools should be strategically located in key areas to effectively shorten students' commuting distances and significantly enhance regional educational service accessibility. Second, we extend the group-based schooling model. It is recommended to extend high-quality educational consortium models to areas with weaker educational resources. Through "flagship school + new school" or "flagship school + underperforming school" partnerships, the radiating effect of quality educational resources can be achieved. Priority consideration should be given to establishing branch campuses of high-quality schools in townships with relatively insufficient educational resources, such as Cuigezhuang and Jinzhan. Third, we improve the transportation shuttle service system.To address long-distance commuting needs, optimize school bus routes and public transit connections. Focus on improving bus stop layouts near newly built schools and rationally planning school bus routes to ensure safe and convenient commutes for students.

Although this study examines the spatial accessibility of primary schools in Chaoyang District, revealing imbalances in the spatial distribution of primary education resources and proposing corresponding optimization suggestions, certain limitations remain. Primarily, data constraints exist: the analysis focuses solely on primary schools in Chaoyang District without considering integrated schools. Including integrated schools would yield more precise results. Secondly, the sample size is limited. This study analyzed data from 65 schools, while the Chaoyang District Education Commission reports 68 primary schools in the district. However, the "2024 Chaoyang District National Economic and Social Development Statistical Bulletin" lists 64 primary schools, indicating a discrepancy. Addressing these data inconsistencies will be a focus for future research improvements.

This study analyzes the spatial accessibility of primary schools in Chaoyang District, revealing imbalances in the spatial distribution of educational resources and proposing optimization strategies. Nevertheless, several areas warrant improvement. First, limitations exist in data coverage. The study focuses solely on primary schools within Chaoyang District, excluding integrated schools from the analysis. Incorporating the educational resources of integrated schools would enhance the comprehensiveness and accuracy of the findings. Second, the accuracy of the sample data requires refinement. The study utilized a sample size of 65 primary schools, which differs from official data: the Chaoyang District Education Commission reports 68 primary schools in the district, while the Chaoyang District 2024 Statistical Bulletin on National Economic and Social Development records 64.Such discrepancies may impact the precision of research findings. To address these limitations, future studies should focus on the following improvements: First, expand the scope of research subjects to include integrated schools within the analytical framework. Second, further verify and standardize foundational data sources to ensure the accuracy and authority of research data. These enhancements will contribute to elevating the scientific rigor and practical guidance value of research outcomes.

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