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Spatial Pattern of Compulsory Education Resources in Shijingshan District of Beijing under the Background of Big Data

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Abstract With the continuous development of promoting high-quality and balanced basic education and the continuous advancement of research on spatial layout of school, it aims to ensure that the public enjoys educational resources fairly. Based on 63 items of POI data of primary and secondary schools in Shijingshan District, Beijing, this study analyzes the spatial layout, degree supply, and coverage of primary and secondary schools in Shijingshan District using three spatial analysis methods: ArcGIS average nearest neighbor, kernel density analysis, and standard deviation ellipse. The results show that the spatial layout of primary and secondary schools in Shijingshan District, Beijing is characterized by overall clustering: the central region is high-density distribution, while the eastern and western parts are scattered. Moreover, this spatial structure continues to develop along the northwest-southeast direction. Although the high-density population areas in the nine streets correspond to the high-density distribution of schools, the service scope of primary and secondary schools does not cover all residential areas, and the distribution of residential areas within the coverage range is uneven. At the same time, the actual degree supply in Shijingshan District is insufficient.

Keywords POI data, Spatial analysis, Educational resources, Coverage
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The Central Committee of the Communist Party of China proposed the long-term goal of building a high-quality education system during the "14th Five-year Plan" period and building a strong education country by 2035 in the *Proposal for the* 14*th Five-year Plan and the Long-range Objectives for* 2035. Shijingshan District is continuously promoting the reform of the science and technology education system, resulting in significant changes in population structure and public education needs. As of the end of 2022, the permanent population of Shijingshan District reached 563,000, with 64,500 children aged 0-14. The number of children has increased by 25% compared to 2010. The continuous growth of the number of children has led to a series of unfair educational phenomena, such as insufficient carrying capacity of basic educational facility space, uneven distribution of educational resources, and large disparities in educational resources. The Education Commission of Shijingshan District released the "14*th Five-year Plan*" *for Education Science Research and Development in Shijingshan District, Beijing* (2021-2025) in March 2022, which proposes to promote high-quality and balanced compulsory education and fair educational resources. Therefore, it plays an important role in promoting fair and balanced development of education by studying the spatial layout and degree supply of primary and secondary schools in Shijingshan District.

Using the characteristics of scale and visualization of GIS spatial analysis, based on the data from 63 POI interest points in primary and secondary schools of Shijingshan District, Beijing, the overall spatial pattern of primary and secondary schools in Shijingshan District is analyzed from three aspects: spatial layout, degree supply, and school coverage. This paper could provide more accurate reference for the optimization and adjustment of education resources in primary and secondary schools of Shijingshan District and the planning and site selection of future primary and secondary schools, and promote the rational distribution and fairness of educational resources.

1 Research area and data sources

1.1 Overview of the study area

The research area is Shijingshan District, which is located in the western part of Beijing. It is an important node in the urban development and construction in the western part of the capital, with an area of 84.38 km^2. It includes nine streets, including Lugu Street, Babaoshan Street, Laoshan Street, Bajiao Street, Gucheng Street, Pingguoyuan Street, Jinding Street, Guangning Street, and Wulituo Street.

1.2 Data sources

The data in this paper mainly includes three types: POI interest point data, administrative division data, and population data. The POI interest point data mainly includes POI interest points of primary and secondary schools, and POI interest point of residential unit. These POI data are mainly obtained from the open API interface of Baidu Maps, with a total of POI data of 39 primary schools (Fig.1), 24 secondary schools (Fig.2), and 327 residential areas (Fig.3) obtained. Moreover, the POI data is corrected through Baidu Maps and converted to WGS1984 coordinates in ArcGIS10.6 for analysis and research. The administrative division data is sourced from the National Geospatial Data Cloud, and the resident population data of each street is obtained and summarized from the Seventh National Population Census Bulletin of Shijingshan District.

2 Research methods

2.1 Kernel density analysis method

Kernel density analysis is the process of calculating the density of discrete points within a certain search window and using it as the center value of that window to generate a continuous density surface of point element space, in order to display their spatial characteristics and trends. It provides an intuitive display effect on discrete points that are difficult to reflect their spatial trends on the graph. The higher the kernel density, the denser the distribution of point elements[6].

2.2 Average nearest neighbor method

The average nearest neighbor is the nearest neighbor ratio calculated based on the average distance between each element and its nearest neighbor element in spatial statistics, which is reflected as the ratio of the "average observation distance" to the "average expected distance"[7]. By calculating the distance between the POI

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locations of secondary and primary schools in Shijingshan District, Beijing, the average nearest neighbor distance (average observation distance) of the schools can be obtained, which can be used to identify the degree of spatial distribution of primary and secondary schools in Shijingshan District. If the average value is less than the average distance (namely the average expected distance) in the assumed random distribution, the nearest neighbor ratio ANN<1, and it indicates that the element distribution of primary and secondary schools is a clustering element. On the contrary, if the nearest neighbor ratio ANN>1, it indicates that the element distribution of primary and secondary schools is dispersed. Meanwhile, the Z-value score and P-value results can indicate whether the concentration of primary and secondary schools is significant, which can be used to determine whether the null hypothesis is accepted.

2.3 Standard deviation ellipse method

The standard deviation ellipse method can measure the spatial layout characteristics of geographic features, and this method has been widely applied in various fields. The larger the difference in values between the long and short half axes, the more pronounced the directionality of the distribution of primary and secondary schools. On the contrary, if the long and short axes are closer, it indicates less obvious directionality. If the long and short half axes are completely equal, it means there are no directional features[6]. Therefore, the standard deviation ellipse method can comprehensively measure the dispersion, concentration area, and development trend of the spatial layout of primary and secondary schools in Shijingshan District, Beijing.

3 Spatial distribution characteristics of primary and secondary schools in Shijingshan District

3.1 Overall spatial distribution characteristics of primary and secondary schools

The average nearest neighbor analysis method is used to study the clustering and dispersion characteristics of primary and secondary schools, to achieve the quantification of the clustering and dispersion degree of primary and secondary schools in Shijingshan District.

From Fig.3, it can be seen that the nearest neighbor ratio in primary and secondary schools is 0.739 816, which is less than 1 and close to 1. Therefore, the overall spatial distribution of primary and secondary schools in Shijingshan District is concentrated. The Z score of primary and secondary schools in this analysis is less than 0, and the P value is less than 0.1, indicating a high possibility of randomly generating this clustering pattern.

3.2 Spatial structure pattern of primary and secondary schools

The overall spatial distribution pattern is analyzed using kernel density analysis, and the natural discontinuity classification method is used to analyze the spatial distribution pattern of primary and secondary schools in Shijingshan District, Beijing. The results show that the high-density red areas of primary and secondary schools are concentrated in Bajiao Street, but the orange secondary density areas of primary schools include Bajiao Street and Lugu Street. The orange secondary density areas of secondary schools are distributed in Bajiao Street, Babaoshan Street, Pingguoyuan Street, and Jinding Street, indicating that primary schools are distributed in multi-point concentration while secondary schools are distributed in single point concentration. But the kernel density of primary and secondary schools in Wulituo Street, Guangning Street, and Gucheng Street is relatively low (Fig.4−5). At the same time, from the population density distribution map of various streets in Shijingshan District (Fig.6), it can be seen that Jinding Street, Bajiao Street, and Babaoshan Street have higher population density, while the corresponding Wulituo Street, Guangning Street, and Gucheng Street have lower population density values. In summary, primary and secondary schools in Shijingshan District have a spatial structure with a central high-density distribution and scattered distribution from east to west. Moreover, kernel density of the spatial distribution of primary and secondary schools is positively correlated with the population distribution density of each street.

3.3 Distribution trend of primary and secondary schools

By analyzing the standard deviation ellipse of the spatial distribution of primary and secondary schools in Shijingshan District, the direction of spatial distribution of primary and secondary schools can be obtained. According to the standard deviation ellipses in Fig.7 and Fig.8, the rotation angle of standard deviation ellipse of the primary school POI is 115.02°, and the length of the long axis is 0.050 741, and the length of the short axis is 0.019 192; the rotation angle of standard deviation ellipse of secondary school POI is 118.87°, with a long axis length of 0.046 769 and a short axis length of 0.015 426. There is a significant difference in the length of the long and short axes between secondary and primary schools, indicating a clear directionality in the spatial distribution of primary and secondary schools. The results indicate that the current and future spatial distribution of primary and secondary schools in Shijingshan District mainly follow the northwest−southeast direction. At the same time, comparing the standard deviation ellipses of primary and secondary schools with those of residential units, it can be found that the distribution trend of POI in primary and secondary schools of Shijingshan District is consistent with that of residential units, both distributed along the northwest−southeast direction.

4 Degree supply characteristics

4.1 Positive correlation between population aggregation and school distribution density

By overlaying the population density map and school density map of the nine streets under the jurisdiction of Shijingshan District (Fig.9), it can be seen that among the nine streets, Babaoshan Street, Bajiao Street, and Laoshan Street have higher density of primary and secondary schools, and the population density of these three streets is also relatively high. Therefore, the results show that there is a positive correlation between density of primary and secondary schools and population density in Shijingshan District, and this result is consistent with the kernel density analysis of POI in primary and secondary schools in Shijingshan District, all of which are more significant in Babaoshan Street, Bajiao Street, and Laoshan Street. At the same time, the data of population and school density are summarized and stacked on the same graph for quantitative display (Fig.10), which can provide a more intuitive view of the density data of schools and population.

4.2 Degree supply characteristics

The population agglomeration density in Shijingshan District is positively correlated with the distribution density of schools, but it cannot reflect the matching between the number of schools and the population, namely the characteristics of degree supply. The boundary between supply and demand is defined by the positive and negative values of degrees. A positive degree value indicates that the degree supply meets the demand, while a negative degree value indicates the opposite result. Based on six times of the birth rate (6.30%) of the permanent population in Shijingshan District,

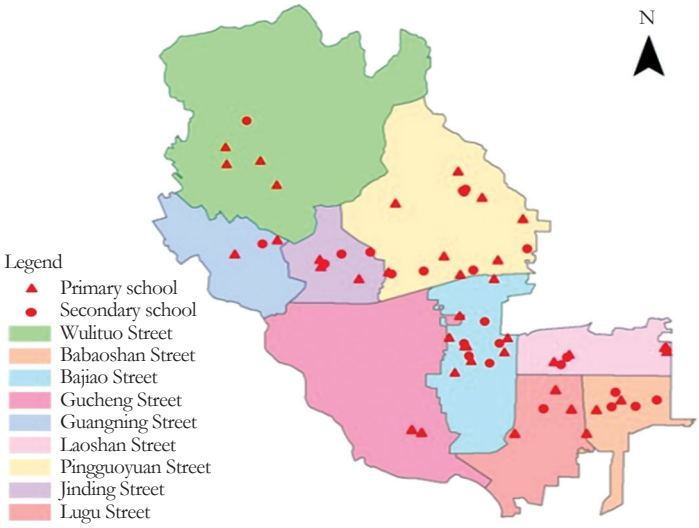

Fig.1 POI distribution of primary and secondary schools in Shijingshan District

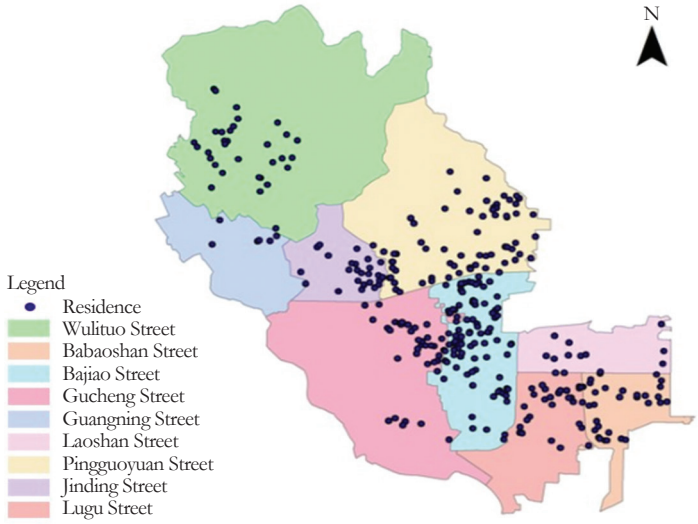

Fig.2 POI distribution of residential areas in Shijingshan District

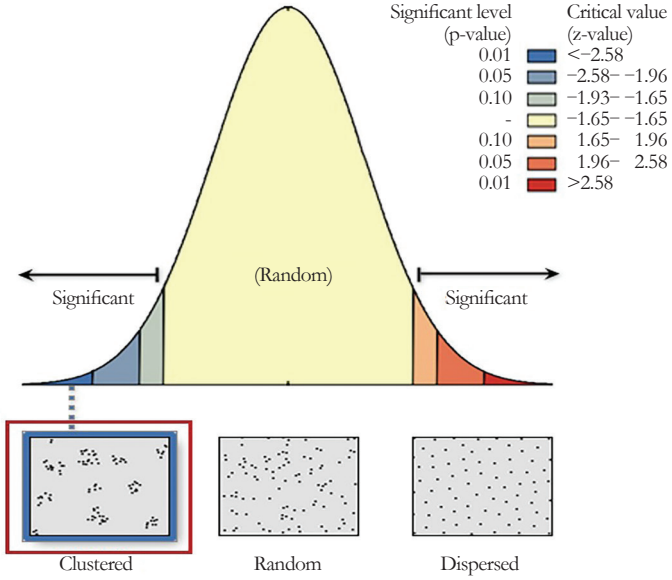

Fig.3 Analysis of the nearest neighbor in primary and secondary schools

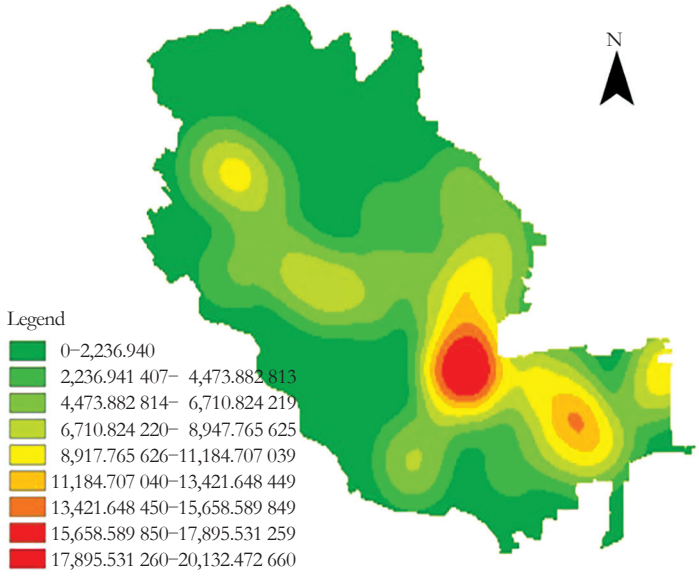

Fig.4 Kernel density analysis of primary schools in Shijingshan District

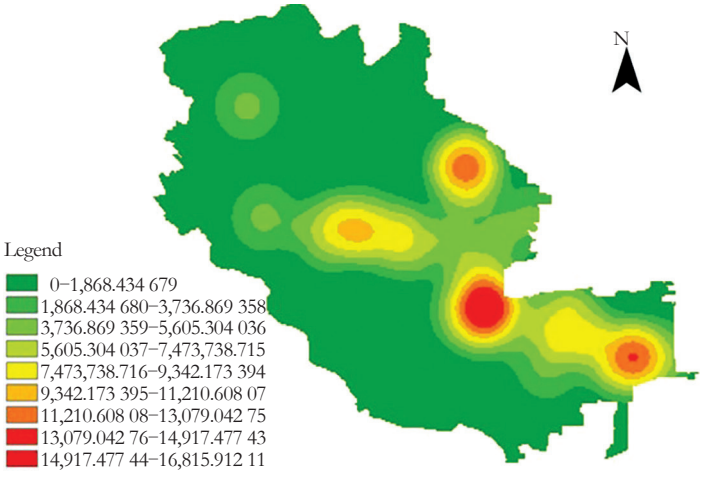

Fig.5 Kernel density analysis of secondary schools in Shijingshan District

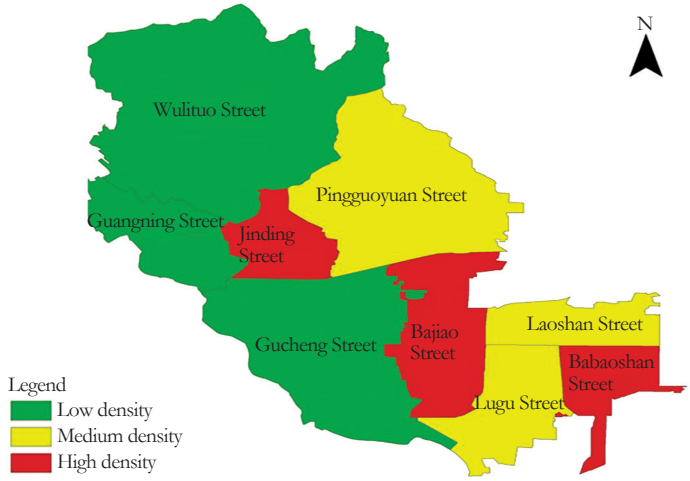

Fig.6 Population density distribution in Shijingshan District

Beijing in 2021, the enrollment population is calculated. In addition, according to the requirements of the *Planning and Design Standards of Urban Residential Area* and the *Design Specification for Primary and Secondary Schools*, the average land area for urban primary schools is 7,000 m^2, with an average student area of 9.3 m^2/person[8]. The calculation formula for degree supply and demand is:

Degree requirement=Number of permanent residents×6.30%×6 (1)

Degree supply=7,000/9.3×Number of schools (2)

Degree value=Degree supply-Degree requirement (3)

According to the calculation formulas (1) to (3) of degree supply and demand, the degree supply and demand situation in Shijingshan District can be calculated. If the degree value in Shijingshan District is less than 1, it indicates that the current educational needs of the population can not be met.

5 Coverage characteristics of primary and secondary school services

5.1 Low coverage efficiency of primary and secondary school services

According to the definition of the service scope for primary and secondary schools in the *Design Specification for Primary and Secondary Schools* (GB 50099−2011) and the *Planning and Design Standard of Urban Residential Area* (GB 50180−2018), the service radius for primary and secondary schools is 500 and 1,000 m respectively. In reality, most children can reach the school within 15 min. Based on the average walking speed of children of 3 km/h, it can be inferred that the walking distance for children in 15 min is about 750 m, which is similar to the range of a 15 min living circle. Therefore, according to the requirements of 500 and 1,000 m in the current *Design Specification for Primary and Secondary Schools*, the scope of primary and secondary school services is studied, and the coverage characteristics of primary and secondary schools are analyzed based on the number of residential units within the scope of primary and secondary school services. Using the methods of a 500 m buffer zone for primary schools and a 1,000 m buffer zone for secondary schools, the coverage range of 39 primary schools and 24 secondary schools in Shijingshan District is obtained (Fig.11). The results show that the service coverage range of 500 and 1,000 m for primary and secondary schools in Shijingshan District cannot fully cover all residential units. According to the statistics of the number of residential areas within the coverage range, the primary school service scope covers 228 residential areas, accounting for approximately 69.7%; the service scope of secondary schools covers 271 residential areas, accounting for approximately 82.9%. The results show that the current coverage efficiency of primary schools in Shijingshan District, Beijing is lower than that of secondary schools. At the same time, there are overlaps in the 500 and 1,000 m buffer zones of primary and secondary schools in Shijingshan District, mainly concentrated in schools in the central and eastern regions. To a certain extent, overlap will waste educational resources, while residential areas outside the coverage range enjoy limited educational resources.

5.2 Uneven number of residential areas covered

The coverage of 39 primary schools and 24 secondary schools in Shijingshan District with the number of residential areas within the coverage area are combined using GIS spatial connection. Meanwhile, using the natural discontinuity method, the number of residential areas covered is divided into 5 levels (Fig.12−13). Through statistics, it can be concluded that a primary school in Shijingshan District covers an average of 6 residential areas, while a secondary school covers an average of 12 residential areas. Among them, the areas with high coverage of primary and secondary schools are mainly distributed in Bajiao Street, Jinding Street Street, and Babaoshan Street. In addition, from the frequency statistics chart (Fig.14−15), it can be seen that there is one primary school in Bajiao Street that can cover 65 residential areas, and one secondary school that can cover 180 residential areas. But there are still residential areas that are not covered. Therefore, this result indicates that there is a significant difference in the number of residential areas covered by primary and secondary schools, and the problem of imbalance is more prominent.

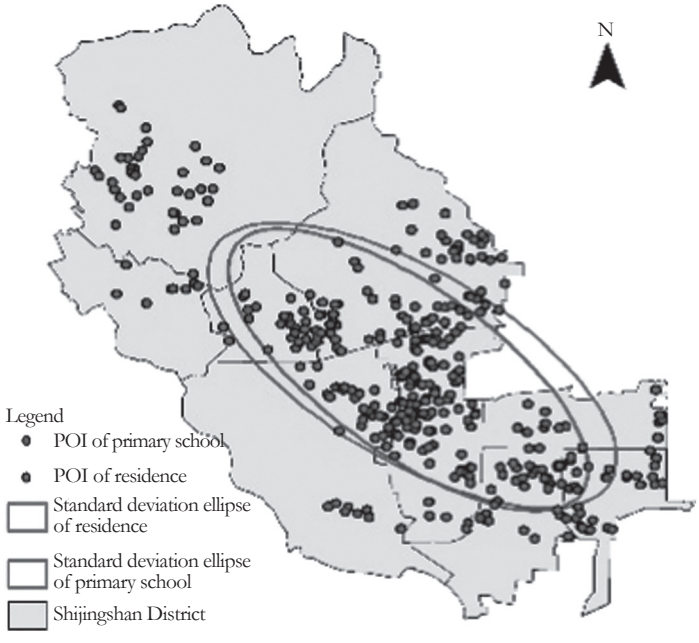

Fig.7 Standard deviation ellipse analysis of primary school

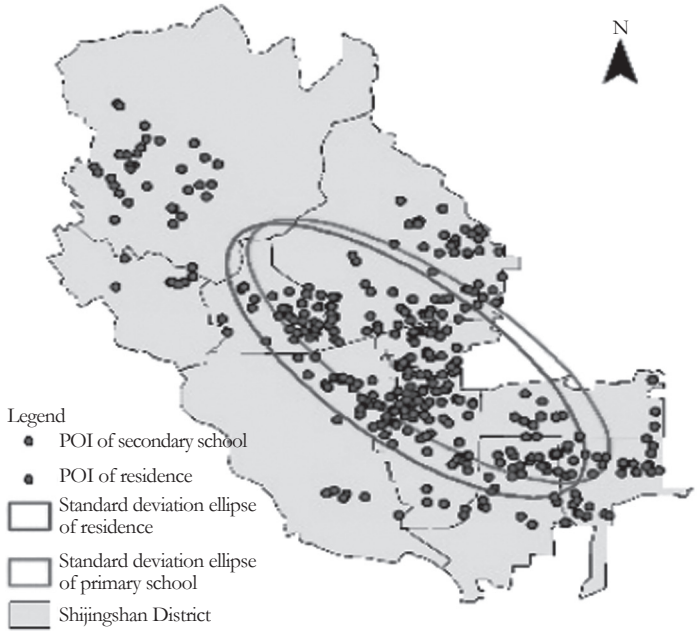

Fig.8 Standard deviation ellipse analysis of secondary school

6 Conclusions

Taking primary and secondary schools in Shijingshan District as the research object, the spatial layout characteristics of primary and secondary schools in Shijingshan District are studied using kernel density analysis, standard deviation ellipse analysis, and buffer zone service radius analysis.

(1) Primary and secondary schools in Shijingshan District, Beijing are clustered, resulting in an imbalance in the distribution of per capita educational resources. The spatial structure is characterized by a central high-density distribution and east–west dispersion, and it mainly develops along the northwest–southeast direction, consistent with the distribution pattern of population density in each street. At the same time, with the continuous evolution of the spatial pattern promoting east–west balance in the *Land Space Plan in Shijingshan District* (2017–2035), the distribution and development direction of primary and secondary education resources along the northwest–southeast is also a reflection of the future development and spatial structure change trend of Shijingshan District.

(2) The number of primary and secondary schools is insufficient and relatively concentrated, which is unable to meet the needs of the current school population. There are significant differences in population density and school distribution among the nine streets under the jurisdiction of Shijingshan District, and there are also significant differences between the supply of primary and secondary schools and the actual demand.

(3) The service coverage efficiency of various primary and secondary schools is relatively low, and the number of residential areas within the coverage area is uneven.

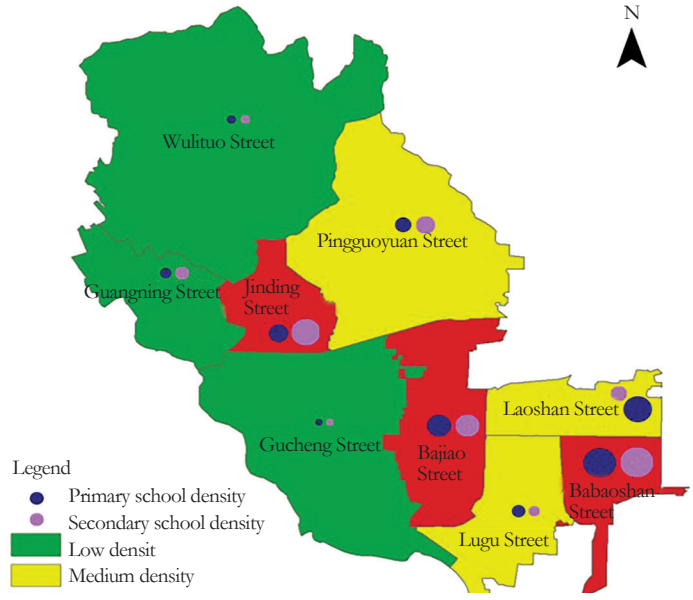

Fig.9 Superimposed analysis of population density and school density

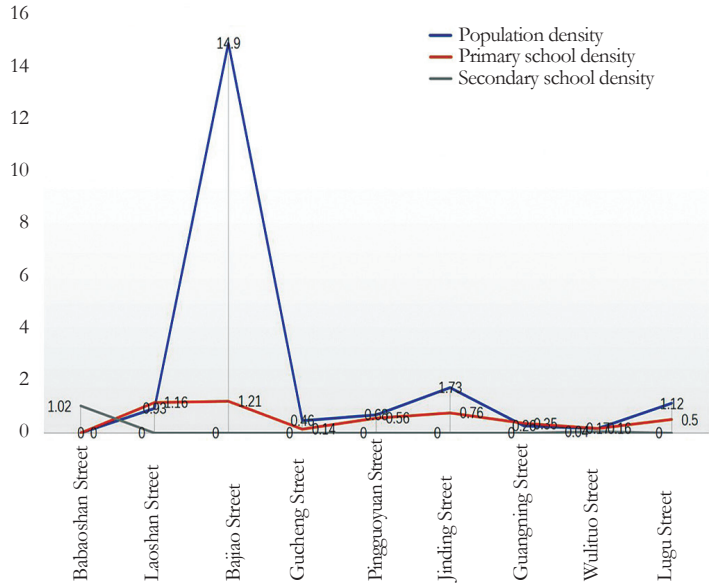

Fig.10 Comparison between population density and density of primary and secondary schools

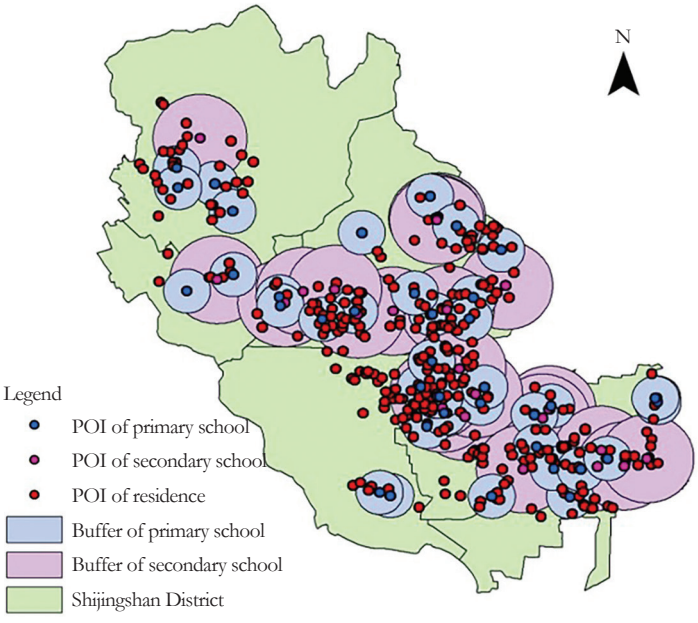

Fig.11 POI coverage range for primary and secondary schools in Shijingshan District

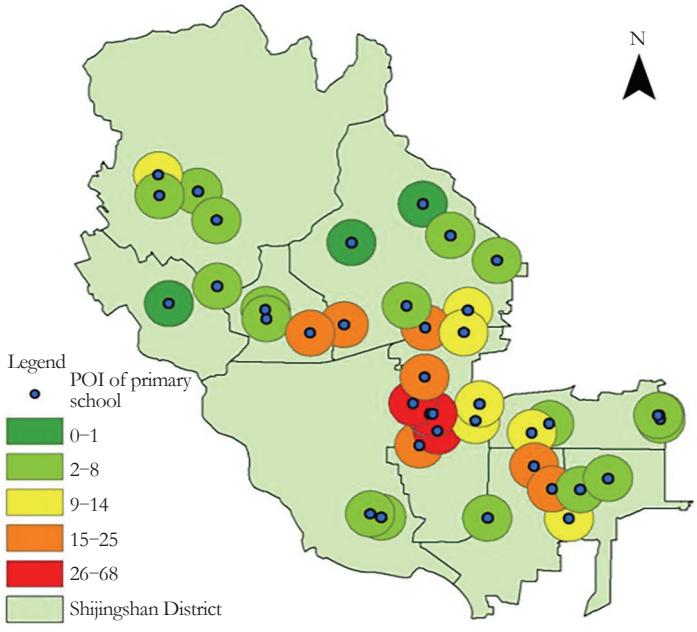

Fig.12 Statistics of residential areas within the coverage range of primary school POI

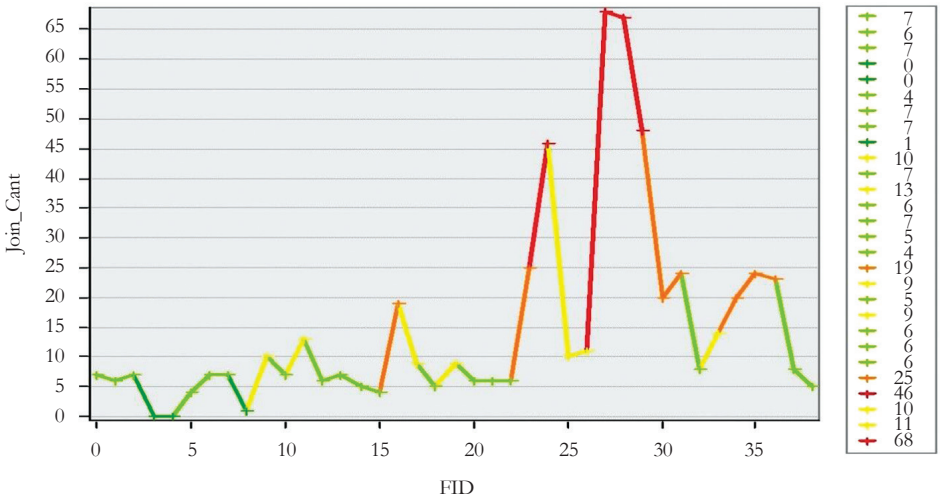

Fig.13 Frequency statistics of residential areas within the coverage area of primary schools

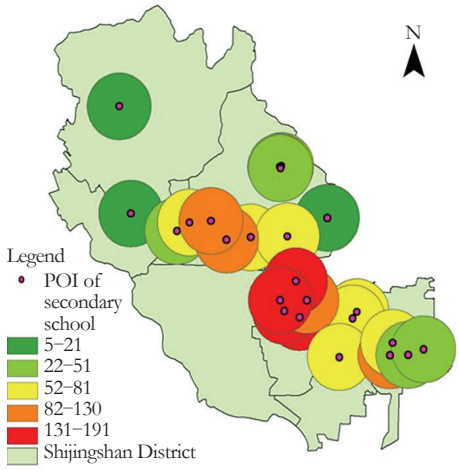

Fig.14 Statistics of residential areas within the coverage scope of secondary school POI

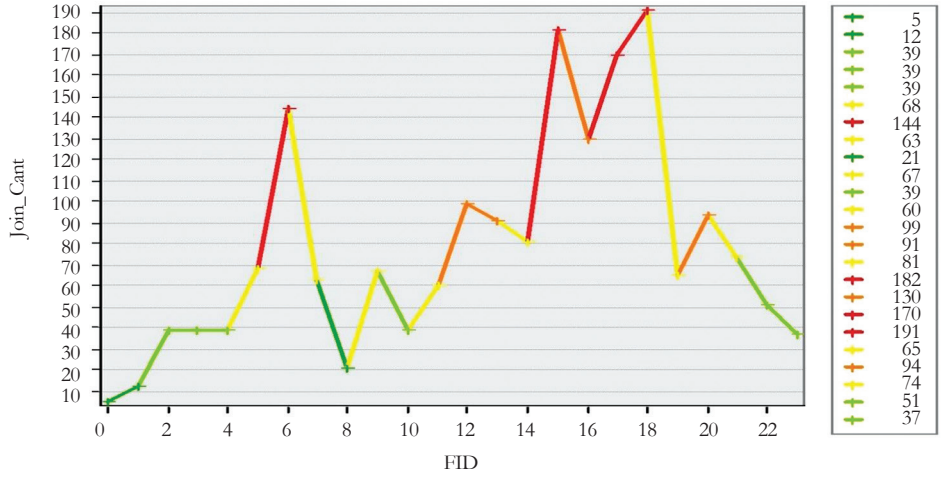

Fig.15 Frequency statistics of residential areas within the coverage scope of secondary school

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