WEP Warwick Evans Publishing

Transactions on Economics, Business and Management Research
ISSN: 2960-1789, eISSN: 2960-2254 | Volume 2
MEHSS 2023

Study on the Spatial Distribution of Public Service Facilities in the Central Districts of Nanjing based on POI Data

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Abstract. Public service facilities are vital components of a city, whose spatial layout pattern closely affects urban residents living in this city. With the rapid transformation of cities and the wide application of big data, conducting simple and visualized research on the spatial distribution of urban public service facilities is meaningful and helpful. Therefore, this paper uses Kernel density analysis method and standard deviation ellipse analysis method, combining with population density and open POI (Point-of-Interest) data, to study the spatial distribution and related matching situation of six types of public service facilities, namely, restaurants, accommodation, shopping, medical care, education and training, and sports and fitness in the central district of Nanjing. The results show that: (1) the layout of various types of public service facilities shows a kind of style -- "central mixing concentration and edge classification diffusion", meaning relatively dense distribution in the central three districts and relatively scattered distribution in the outer three districts; (2) The elliptical centers of various public service facilities are all located at the junction of the three central districts while the distribution and service scope of medical, catering and accommodation facilities are the widest, and the direction of spatial distribution is northeastern-southwestern; (3) There is a mismatch between the distribution of population density and the distribution of public service facilities in some areas of Gulou District, Qinhuai District, Jianye District and Yuhuatai District. This study can provide theoretical guidance and reference for the future planning of public service facilities in the central districts of Nanjing.

Keywords: Public Service Facilities; POI Data; Spatial Distribution; Central Districts of Nanjing.

1. Introduction

Since the reform and opening up, China's economy has developed rapidly and urbanization has ushered in rapid development, with the urbanization level exceeding 63% by 2020. With the high-quality development and comprehensive strength of cities, employment opportunities have increased, attracting a large number of people to gather in central urban areas. At this stage, the main social contradiction in China has changed to the contradiction between the people's growing need for a better life and unbalanced and insufficient development. As people tend to pursue high-quality life, with the rapid development of urban living service industry, public service facilities are now being built and popularized rapidly.

In order to meet the increasing demand for services in people's daily life, the reasonable layout of public service facilities in the city is especially important. It is of practical significance to study the spatial distribution characteristics of urban public service facilities so as to discover the current possible planning issues, promote the rational layout of facilities and improve the life quality of residents. In recent years, with the massive application of big data in the field of urban and rural planning, scholars devoted to urban research have found that big data technology is important and helpful in the study of related issues. With its characteristics of large-scale calculation and quantitative analysis, big data provides good technical support for quantitative urban research and allows people to grasp the spatial layout and characteristics of cities more intuitively and quantitatively [1,2]. Based on POI data, this paper takes the public service facilities in the central districts of Nanjing as the research object, and tries to explore the spatial distribution characteristics and matching situation by conducting kernel density analysis, standard deviation ellipse analysis, combining with population density, so as to provide a research basis for the reasonable layout of public service facilities in the central districts of Nanjing.

2. Literature Review

Urban public service facilities are the carrier of urban social service industry, which refers to the social infrastructures such as education, medical, cultural and sports, and commercial facilities that are distributed in a dotted pattern and serve the public in the city [3]. Combined with the definition of public service facilities in the existing literature, they can be classified into six categories: restaurants, accommodation, shopping, medical care, education and training, and sports and fitness [4]. In the current process of urban development, the reasonable layout and application of public service facilities play an important role in urban planning and governance and residents' life, in which POI data, as a kind of important point data representing urban spatial facilities, has made certain achievements in the spatial study of public service facilities [5]. At present, many scholars have conducted research on the configuration of public service facilities based on POI data, and the current popular research topics are mainly focused on the following three aspects, namely, the spatial distribution characteristics of public service facilities, accessibility, and configuration evaluation research. First, for the study of spatial distribution characteristics of public service facilities, some scholars analyze the spatial layout characteristics of urban public service facilities based on the POI data by using various spatial analysis methods, and obtain the significant characteristics of public service facilities, which show the aggregated distribution in space [6-10]. Secondly, for the study of accessibility of public service facilities, some scholars analyzed the spatial accessibility and the results indicate that urban public service facilities possess spatial accessibility differences and there is spatial differentiation [11-15]. Finally, for the research on the evaluation of the configuration of public service facilities, such studies mostly focus on the evaluation of convenience, balance or configuration criteria [16-20]. Combined with the theory of living circle division, some scholars have determined objective evaluation standards for the convenience of living in livable cities based on POI data of several different cities. [18,20]

Regarding the spatial distribution characteristics of public service facilities, the existing domestic studies mainly focus on the analysis and evaluation of the spatial pattern of urban public service facilities, without summarizing the general rules behind the distribution characteristics of facilities, and less attention is paid to the distribution of urban public service facilities and other elements. In addition, most of the existing domestic studies focus on a single type of public service facilities, such as education, medical or sports facilities, and there are few studies including comprehensive and comparative analysis of different types of facilities [21]. Based on geographic information POI data, this paper explores the spatial distribution characteristics of six types of public service facilities in the central districts of Nanjing to make up for the lack of mining the spatial distribution pattern of facilities. At the same time, by comparing the spatial correlation degree between the spatial distribution and population density, the spatial allocation of public service facilities and population demand are combined to achieve a close fit between public service facilities and population distribution, promoting reasonable distribution and allocation of public service facilities.

3. Definition of Public Service Facilities and Data Sources

3.1. Definition of Public Service Facilities

Since there is no exact definition of public service facilities, in order to further determine the concept and classification criteria of public service facilities that should be examined in the study, this study collected and analyzed relevant literature, norms and guidelines to clarify the public service needs that guarantee citizens' lives and sort out the concept and types of public service facilities that are closely related to public life.

According to *the Code for Planning and Design of Urban Residential Areas* (GB5018093, 2016 edition), public service facilities include eight categories: education, health care, culture and sports, commercial services, finance, post and telecommunications, community services, municipal utilities, administration and others.

According to *the Technical Guide for Community Life Circle Planning* (TD/T 1062-2021), community service facilities in urban community life circles contain eight categories of lifelong education, cultural activities, sports and fitness, administration, commercial services and others.

Based on the above and the theoretical research of existing literature, combining the types of facilities closely related to citizens' life services, the definition of public service facilities is finally determined that public service facilities refer to various service facilities built in public areas to meet citizens' daily needs, including (1) dining facilities of various levels mainly for providing daily meals for the public; (2) accommodation facilities mainly for providing shelter for the public living outside temporarily; (3) shopping facilities mainly for providing shopping services to the public; (4) medical facilities mainly for providing health protection services to the public; (5) educational facilities mainly for providing educational services to the public, such as primary and secondary schools; (6) sports and fitness facilities mainly for providing venues for various sports activities for the public.

Table 1. Classification of public service facilities

Major Category	Minor Category	POI Quantity
Dining	Chinese cuisine, foreign cuisine, snacks and fast food, desserts and beverages, others	10522
Accommodation	Budget chain hotels, hostels, youth hostels, star hotels, others	2173
Shopping	Department stores, convenience stores, supermarkets, shopping malls, others	22044
Medical care	Hospitals, clinics, emergency centres, disease prevention, pharmaceutical sales, others	4549
Education and training	Primary and secondary schools, higher education, training establishments, cultural exhibitions, radio and television, others	4239
Sports and fitness	Ball games, snow and ice sports, water sports, outdoor fitness facilities, fitness centres, others	1913

3.2. Regional Overview and Data Sources

3.2.1. Regional Overview

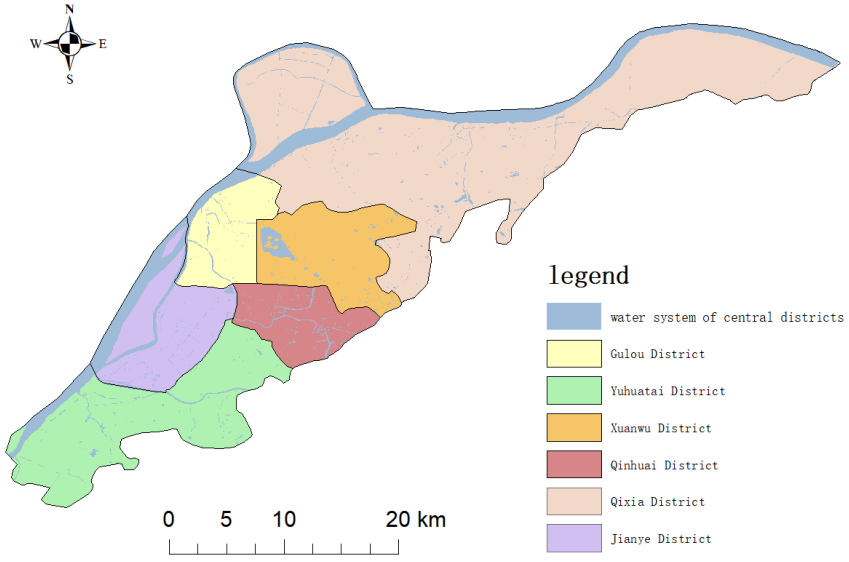

Figure 1. Schematic diagram of the central districts of Nanjing

Nanjing is located in the eastern part of China and the central part of the lower reaches of the Yangtze River. It is the capital of Jiangsu Province. As a central city in the eastern part of China, Nanjing is

an important research and education base and a comprehensive transportation hub as determined by the State Council. The city has 11 districts with a total area of 6,587.02 square kilometers and a resident population of 9,491,100. This study takes the central districts of Nanjing as the targeting area, which include six districts: Gulou District, Xuanwu District, Qinhuai District, Jianye District, Qixia District and Yuhuatai District. The six districts are located in the central-eastern part of Nanjing and the southern part of the Yangtze River, with a total area of 788.33 square kilometers and a resident population of 4.382 million.

3.2.2. Data Sources

With the POI retrieval service provided by Amap Open Platform API, this study crawled data by programming, and obtained POI data of five types of facilities, namely, dining, accommodation, shopping, medical, and sports and fitness, according to the latitude and longitude range of Nanjing central districts. With total 50,865 items, the study de-weighted, filtered, matched and screened out a total of 41,201 valid data as research samples. And the POI data of education and training facilities, the sixth type of public service facility, came from the official website of Nanjing Education Bureau (http://edu.nanjing.gov.cn/). After de-weighting and screening, the researcher obtained a total of 4,239 valid POI data of education and training facilities. The administrative boundary and population data of the central districts of Nanjing were mainly obtained from *the Nanjing Statistical Yearbook* (2021).

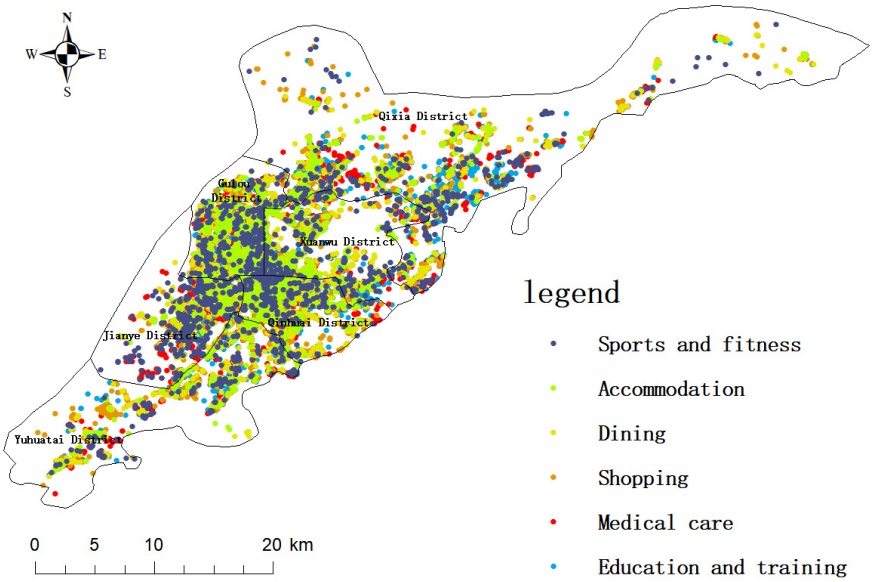

Figure 2. Spatial distribution of public service facilities in the central districts of Nanjing

4. Research Methods

4.1. Kernel Density Analysis Method

This paper analyzes the spatial aggregation of public service facilities in the downtown area of Nanjing mainly using the kernel density analysis method. The analysis used the data including the study boundary of Nanjing and the POI data of public service facilities in the downtown area. Firstly, the administrative boundary data of Nanjing central urban areas obtained from Nanjing Statistical Yearbook was imported into GIS to generate a basic map. After that, the .xls files crawled from the open data platform of Amap were represented as POI point data by adding latitude and longitude coordinates and specifying the coordinate system. Finally, the kernel density analysis was completed by the professional tool to generate a kernel density analysis map of various public service facilities in the central districts of Nanjing.

Kernel density analysis can be used to analyze the characteristics of spatial distribution and the degree of aggregation of geographic information performed as POI point data. The basic principle of kernel density analysis is to use an output raster image element to calculate the distribution density of point or line elements by using core estimation, so as to effectively simulate the aggregation area of various elements. Assume the probability density function to be f, then the kernel density estimation equation can be expressed as [4]:

Where k( ) is the kernel function and h is a smoothing parameter called bandwidth; n is the sample size; d denotes the distance between the estimated point x and the sample observation point .

The POI points in the kernel density analysis map will form a continuous ring-like surface throughout the study area, and the denser the POI points are, the darker the color of the kernel density analysis results will be, indicating the higher degree of aggregation of public service facilities.

4.2. Standard Deviation Ellipse Analysis Method

In this paper, the spatial distribution direction and trend of public service facilities in the central districts of Nanjing are analyzed mainly by using the standard deviation ellipse analysis method. Firstly, on the basis of processing the analysis base map and POI point data and then using the directional distribution tool, the first rank ellipse containing 67% of the elements is selected, and finally the center of the ellipse is expressed as point data by adding latitude and longitude coordinates to generate the standard deviation ellipse analysis map and the graph of analysis parameter results for various public service facilities in the downtown areas of Nanjing.

The basic principle of standard deviation ellipse analysis is to measure the standard distance of a set of point elements on the x and y direction axes respectively, so as to measure the spatial distribution characteristics of the central trend, dispersion and directional trend. The formula for calculating the center of the ellipse is as follows [4]:

where are the coordinates of the center of the ellipse, (,) are the coordinates of public service facility i, and denotes the weights;

where is the azimuth angle and (,) is the deviation between the coordinates of the public service facility I =[() /] / [(() /] and the center of the ellipse;

Where and denote the standard deviation along the long and short axes, respectively, and are equal to the values of the long and short half-axes of the ellipse, respectively.

In the standard deviation ellipse analysis chart, the center of the ellipse indicates the center of public service facilities gathering, the long half-axis indicates the direction of public service facility distribution, the longer the long half-axis indicates the stronger the direction of facility distribution, the short half-axis indicates the range of public service facility distribution, the longer the short half-axis indicates the wider the range of facility distribution, and the azimuth angle indicates the angle of deviation of public service facility distribution.

5. Results Analysis of the Spatial Distribution of Public Service Facilities

5.1. Kernel Density Analysis of Public Service Facilities

The kernel density analysis method is used to analyze the aggregation degree of public service facilities in the central districts of Nanjing, and the results are shown in Figure 3.

(1) From the results of the kernel density analysis map of Nanjing's main urban areas, it can be seen that the distribution of food and beverage facilities is relatively wide, with a trend of spreading outwards from the junction of Xuanwu, Qinhuai and Gulou districts. In addition, the university town near Huanan Road in Gulou District and the area around Nanjing Confucius Temple attraction in Qinhuai District form two higher density gathering places for POI. The university town in Gulou District is home to a large number of young students with a high appetite for

consumption, which can attract a large number of food and beverage type facilities to congregate there. Nanjing Confucius Temple attraction in Qinhuai District, on the other hand, is the most popular tourist attraction in Nanjing, attracting a large number of tourists to spend money here every year. In addition, the surroundings of Nanjing Confucius Temple are also the southern part of the old city, a traditional residential area with a large population, so a high density of gathering centres are formed here. With the exception of the higher density agglomerations that appear near the junction of the three central districts, all other areas show a lower density of sprawl and spread.

(2) The results of Kernel density analysis of accommodation facilities in the main urban areas of Nanjing show they are scattered, but there are three distinct, continuous and similarly sized agglomeration centres. These are Gulou in Gulou District, Xinjiekou at the junction of the three districts, and the surrounding areas of the old southern part of the city in Qinhuai District. Meanwhile, the density of facilities spreads outwards from these three locations, with which of Qinhuai District being the most extensive. This is due to the fact that 100 years ago, the old southern part of Nanjing was exactly the population concentration area. As time goes by and the city expands, governmental, educational and medical facilities settled in the northern Gulou and Xuanwu districts, where land was relatively plentiful, driving population migration and eventually creating the current concentration centres of accommodation facilities. Other than that, most of the areas show a lower density spread.

(3) The results of Kernel density analysis of shopping facilities in the main urban areas of Nanjing show that the distribution pattern of shopping facilities is similar to that of restaurants, with a wide distribution and a tendency to spread outwards from the junction of Xuanwu, Qinhuai and Gulou districts. However, the difference is that there are several secondary high-density gathering centres for shopping facilities, such as Wanda Plaza in Jianye District and Hongyang Home Furnishing Expo Centre in Yuhuatai District, where there are more shopping categories and a wider distribution than for restaurants. Large commercial complexes and furniture-based shopping facilities such as Wanda Plaza tend to choose new urban sites with larger plots and lower land prices due to site requirements and land price constraints, thus creating a difference in spatial distribution with food and beverage facilities.

(4) The results of Kernel density analysis of education and training facilities in the main urban areas of Nanjing show that education and training facilities are clustered in high-density and spread outwards continuously. Unlike the spatial distribution pattern of other facilities, the clustering centre of education and training facilities is prominent in the Gulou district, which is the traditional cultural and educational centre of Nanjing, with many universities located such as Nanjing University, Southeast University and Nanjing Normal University. In addition, Nanjing Forestry University, Nanjing University of Technology, Nanjing Agricultural University and Nanjing University of Aeronautics and Astronautics are clustered in Qinhuai District and Xuanwu District, so there is a secondary high density of educational and training facilities in this area. Besides, there are many primary and secondary schools in the vicinity, which is also the reason for the high concentration and density of education and training facilities.

(5) The results of Kernel density analysis of medical facilities in the main urban areas of Nanjing show that the spatial distribution of medical facilities is very wide, mainly concentrating at the junction of the three central districts, showing a large grouping of clusters and spreading outwards in a higher density, more extensive and continuous manner. The Gulou District is the most densely and widely distributed, with higher density clusters in the northern part of Jianye District and the southern part of Qixia District, which are at the border areas with Gulou District. However, in the peripheral areas, the spread of medical facilities is in a low density and dispersed spread. This is due to the fact that Gulou District is the main medical centre developed by Nanjing Government, and the spatial distribution pattern of medical facilities generally spreads outwards from the centre, resulting in higher density agglomerations in the border areas between other districts and Gulou District.

(6) The results of Kernel density analysis of sports and fitness facilities in the main urban areas of Nanjing show a tendency to spread outwards from the junction of Xuanwu District, Qinhuai District and Gulou District and to form a large concentration of POI in the centre. The high density of young students in the university town of Gulou District have led to the rapid development of sports and fitness facilities in the surrounding area, resulting in the most extensive and dense distribution. As Nanjing has hosted major sporting events such as the National Games, Asian Youth Games and Youth Olympic Games in the Youth Olympic Park and Olympic Sports Centre, sports and fitness facilities are mostly clustered in these two locations, creating two high-density centres.

Comparing the spatial distribution of the six types of public service facilities in the main urban areas of Nanjing, it can be seen that the overall distribution of the six types of public service facilities is centred on the junction of the three central districts and spreads outwards, and there is a clear spatial overlap in the gathering places of the various types of public service facilities, in other words, they are all concentrated at the junction of the three central districts.

The area where the three districts of Xuanwu District, Qinhuai District, and Gulou District join is Xinjiekou, which is the earliest area of Nanjing in terms of urban formation and development, and it's also the earliest commercial centre of the city. Built in 1929 to welcome the coffin of Mr. Sun Yat-sen, Zhongshan Road is the city axis of Nanjing, the important node of which is Xinjiekou, bridging the old and new city areas at that time. It is not only convenient for transportation, but also has a deep cultural heritage, which thus was the perfect place to create a new commercial centre. *The Capital Plan*, an urban planning programme that has had a major impact on the modern Nanjing's urban areas, mentions that Xinjiekou will be a key commercial area. This area has been developed over the years and has set the pattern and direction for the development of today's central districts of Nanjing, which is still the most prosperous area of the city today. In the vicinity of Xinjiekou, as the population is densely distributed, the level of economic development is high, transport is convenient and the construction of public services has undergone a long period of accumulation, a high-density gathering centre has been formed.

In addition to the Xinjiekou area at the junction of the three districts, both Gulou District and Qinhuai District show a higher density of agglomeration, located in University Town of Gulou District and Nanjing Confucius Temple of Qinhuai District respectively, indicating that cultural and educational centres and tourist destinations also drive the rapid construction of public service facilities.

It is worth noting that although Xuanwu District is located in the old areas of the city, most of its public service facilities are clustered at a low density because of the isolation brought by Zijinshan Mountain and Xuanwu Lake.

Finally, the three outer districts of Jianye District, Yuhuatai District and Qixia District have almost no high-density agglomeration centres, , most of which show scattered distributions and a low-density outward spread. On the one hand, because Qixia District, Pukou District and Yuhuatai District all cover a larger area, the density of facilities is lower accordingly and the degree of agglomeration is relatively low; on the other hand, because the three peripheral districts are not old urban areas and were developed lately, thus various public service facilities have not yet been fully popularised and constructed Therefore, the subsequent planning should focus on the reasonable allocation of public service facilities. This indicates that the layout of various public service facilities in the central districts of Nanjing is relatively uneven, among which the three peripheral districts are under-constructed and need further integrated planning and development in the future.

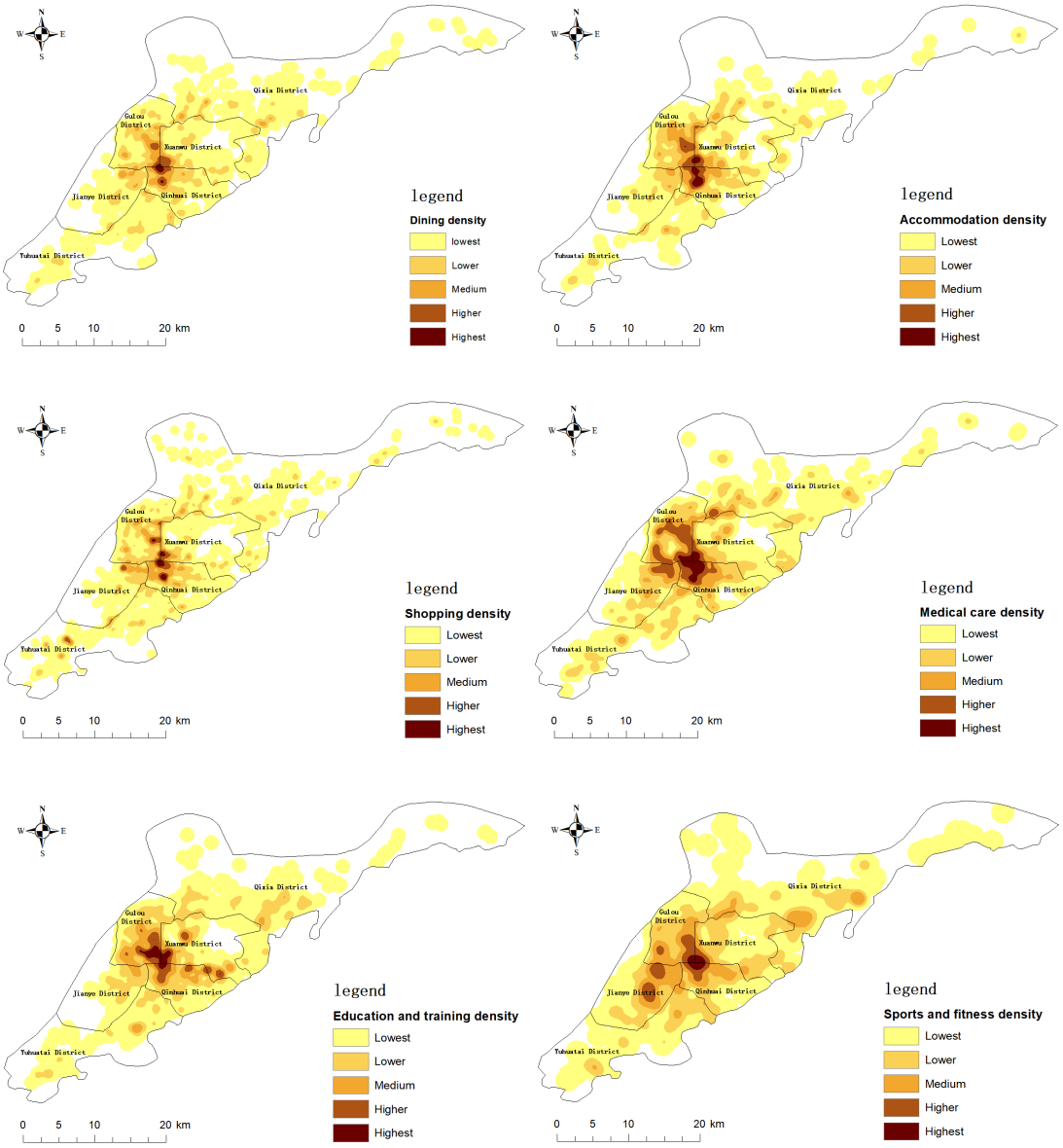

Figure 3. Kernel density analysis of various public service facilities in the central districts of Nanjing

5.2. Standard Deviation Ellipse and Centre-of-mass Distribution Analysis

The spatial distribution characteristics and trends of public service facilities in the central districts of Nanjing were further analyzed by using the standard deviation ellipse analysis method. The research found that an ellipse with 24 km as the long semi-axis and 10 km as the short semi-axis at 118°E, 32°N could encompass about 67% of the public service facilities in the central districts of Nanjing. The clustering area of public service facilities was roughly distributed in a northeast-southwest direction, with all types of facilities concentrating and expanding along this direction. The ellipse covered the majority of the central urban areas of Nanjing. The centre of the ellipse of public service facilities was located roughly at the junction of the three central districts, with a slight bias towards Xuanwu District, indicating that this area had the densest distribution of public service resources and was the centre of gravity in the spatial distribution of public service facilities in Nanjing's central urban areas. The map showed that the Xinjiekou commercial centre and many residential areas were located in this area, which was the most densely populated and thus required the most public service facilities.

In recent years, in addition to the development of the old urban area around the junction of the three central districts, Nanjing Government has also begun to focus on the construction of three peripheral districts, such as Jianye District, which will become a financial services and cultural and sports centre, Yuhuatai District, which will become a software and information services centre, and Qixia District, which will become a scientific and educational research and shipping logistics centre, and new expansion sites also tend to be developed in these three districts.. In addition, the Yangtze River and the city's main roads are influencing the expansion of various public service facilities along the northeast-southwest trend. The results of the standard deviation ellipse parameters for various public service facilities show that the short semi-axis of medical, accommodation and catering facilities is relatively long, while the short semi-axis of shopping, education and training and sports and fitness facilities is relatively short. As medical, catering and accommodation facilities serve residents as their daily needs, their effective spatial distribution has an important impact on the livelihood security of residents, while shopping, education and sports serve specific groups of people and are not the basic needs of all residents, and thus the scale of their construction can be slightly lower than that of the other three types of facilities. Therefore, the spatial distribution of medical, catering and accommodation facilities is on a larger scale and serves a wider range of people than the other three types of facilities.

The results of the ellipse analysis reveal that the spatial distribution of public service facilities in the central districts of Nanjing is uneven, with Qixia District and Yuhuatai District covering a smaller area, indicating a lower density of distribution of public service facilities, which can be optimized in three aspects: theoretical research, spatial planning and facility management.

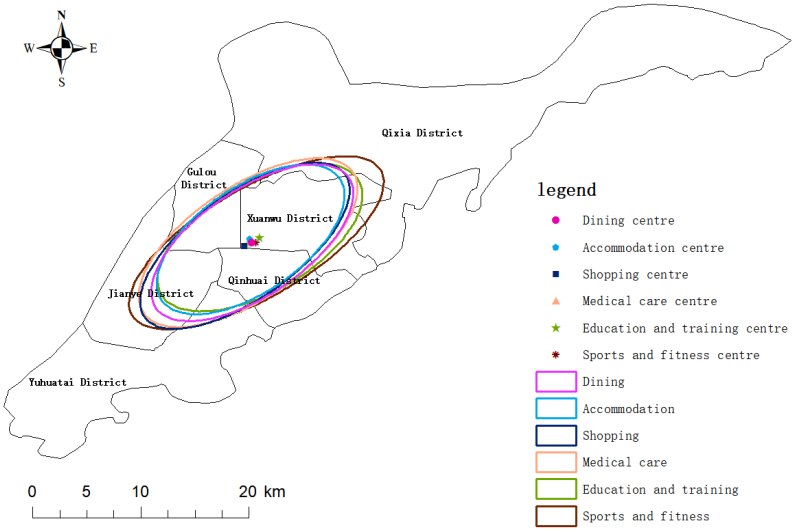

Figure 4. Ellipse analysis of the standard deviation of various public service facilities in the central districts of Nanjing

Table 2. Results of standard deviation ellipse analysis method of various public service facilities in the central districts of Nanjing

Type of public service facility	Central coordinates X	Central coordinates Y	Long half-axis/km	Short half-axis/km	Azimuth/ degree
Dining	118.788556	32.048049	19.44	9.66	55.92
Accommodation	118.787155	32.050812	18.03	9.82	55.35
Shopping	118.782396	32.045486	20.63	9.12	54.41
Medical Care	118.785082	32.048191	21.01	9.62	55.98
Education and Training	118.794789	32.052455	18.72	9.20	59.99
Sports and Fitness	118.791926	32.048016	23.74	9.27	59.57

5.3. Evaluation of the Spatial Matching of Public Service Facilities

Public service facilities are various public and service facilities that provide public service products for the public and are an indispensable part of public life. Therefore, the fit between their spatial distribution characteristics and the distribution of population density has an important impact on the level of convenience of public life. This paper focuses on comparing the relationship between the results of Kernel density analysis of public service facilities and the distribution of population density in the central districts of Nanjing, and derives the spatial support of public service facilities, the results of which are shown in Figures 5 and 6.

The analysis found that the results of Kernel density analysis of public service facilities in the central urban areas of Nanjing roughly overlap with the distribution of population density, and both show a tendency to gather towards the city centres. It also shows a high density of gathering at the junction of Gulou District, Xuanwu District and Qinhuai District, but not an exact correspondence relationship. Some areas have high population density, but the distribution density of public service facilities is low and they are insufficient to meet public demand. For example, the Xiaguan Binjiang Area in Gulou District, the vicinity of Mochou Lake in Jianye District and the Southern Old City in Qinhuai District are all traditional residential areas in Nanjing, where a large number of people congregate in high-density. Due to the closure of railway stations and other transportation nodes and the continuous development of new cities, these old areas are facing a weakened vitality and difficulties in renewal, resulting in a relatively low level of public service facility density. At the same time, there are also some areas with a high density of public service facilities but a low population density. For example, the Xinjiekou Area in Qinhuai District and the vicinity of Nanjing Confucius Temple are in relatively high-level construction of various public service facilities, as they are the commercial centre of Nanjing and a well-known tourist attraction, although fewer people live here on weekdays but they can briefly gather a large number of people to spend money on weekends and holidays.

In addition, as mentioned above, the spatial distribution of public service facilities in some of the border areas of the three central districts is at a high level in relation to the distribution of population density, like Nanjing University Campus in Gulou District, Southeast University Campus in Xuanwu District and Chaotian Palace in Qinhuai District These areas are traditional residential areas with a large resident population, and because of their proximity to university campuses and commercial centres, a diverse group of people such as university students and consumers gather, contributing to a high level of urban vitality over time and leading to the constant renewal and improvement of public service facilities around them.

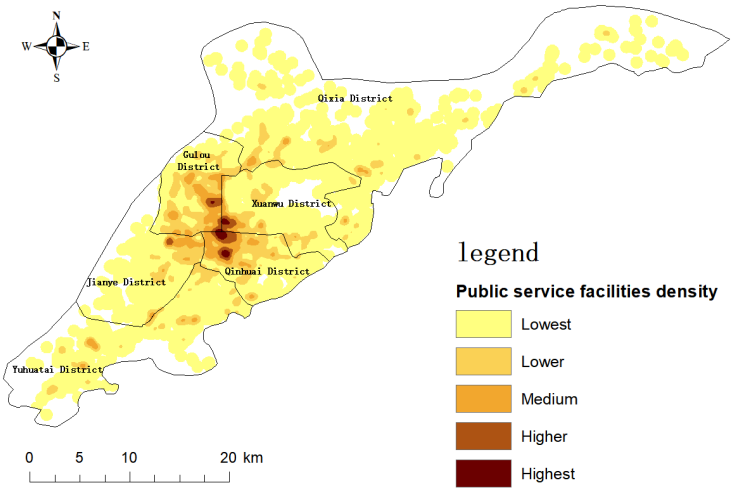

Figure 5. Kernel density analysis of public service facilities in the central districts of Nanjing

On the whole, although the distribution of population density and the spatial distribution of public service facilities match in most areas, there are still some problems with the spatial matching of public service facilities in the central districts of Nanjing. For example, there are some areas with high population densities in Gulou District, Qinhuai District and Jianye District, but the lack of renewed vitality has led to a lack of public service facilities at the appropriate level accordingly. In Yuhuatai District, there are some high-density gathering points for public service facilities, but the overall population density is low. This phenomenon is probably due to the large size of this district, resulting in an overly scattered distribution of public service facilities, which can be addressed in the subsequent spatial planning and facilities allocation process.

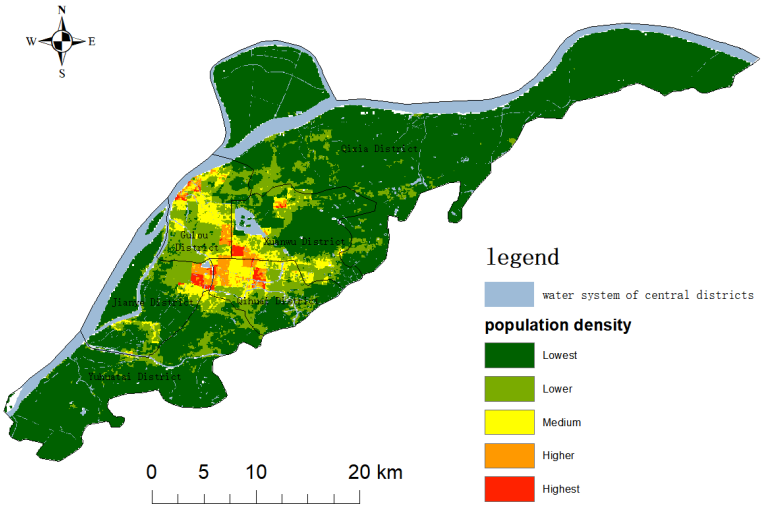

Figure 6. Analysis of the population density in the central districts of Nanjing

6. Conclusion and Outlook

6.1. Conclusion

In this paper, based on the POI data of six types of public service facilities (restaurants, accommodation, shopping, medical care, education and training, sports and fitness) in the central districts of Nanjing, which have been checked and processed, the researcher used kernel density analysis, standard deviation ellipse analysis and evaluation of the spatial support of public service facilities to analyze and interpret the spatial distribution characteristics, spatial distribution directions of facilities and spatial support of public service facilities in the central districts of Nanjing respectively. The main conclusions are as follows:

(1) The overall spatial distribution pattern of the six types of public service facilities in the central urban areas of Nanjing shows a layout pattern of "mixed concentration at the centre and diffusion at the edges", with the junction of the three central districts as the centre for outward diffusion, and there is an obvious overlap in the spatial distribution of various types of public service facilities. Among them the Xinjiekou Area at the junction of the three central districts has the most obvious clustering characteristic. The clustering characteristics of the three peripheral districts differ to a certain extent due to the different distribution of facilities.

(2) The distribution of the six types of public service facilities in the central districts of Nanjing is generally distributed in a northeastern to southwestern direction, with all types of facilities clustering and expanding along this direction. The centre of the ellipse is located roughly at the junction of the three central districts, with a slight bias towards Xuanwu District, indicating that this is the centre of gravity in the spatial distribution of public service facilities in Nanjing's central urban areas. Medical, catering and accommodation facilities have the largest spatial distribution scale and the widest service range due to their service-oriented

nature.

(3) Overall, although the distribution of population density and the spatial distribution of public service facilities match in most areas, there is also a mismatch in the spatial distribution of public service facilities in Nanjing's central urban areas. For example, some areas in Gulou District, Qinhuai District and Jianye District have high population densities, while the concentration of public service facilities is low. In Yuhuatai District, there are some high-density gathering points for public service facilities, but the overall population density is low on the contrary.

As the population size of Nanjing's central urban areas continues to rise, land resources are gradually becoming tighter. How to renew and optimize facilities on built-up urban land to provide high-quality living services for the general public is the main challenge faced by Nanjing Government in the future. According to the results of this study, Nanjing can optimize the spatial layout of living service facilities in the following two ways. The first is the renewal of facilities in the old urban areas. The renewal and construction of facilities in this area will not only facilitate the life of residents, but also become an attraction point to achieve population gathering and vitality reconstruction. Secondly, the public service facilities in each district could be coordinated according to the degree of population gathering, and those areas with a high degree of population gathering but a lack of public service facilities will be supplemented and optimized to achieve a reasonable reallocation of resources.

6.2. Research Shortcomings and Prospects

This study is constrained by objective factors such as basic data and the author's professional know-how, and there are still some shortcomings:

(1) This study has conducted a spatial analysis of public service facilities based on the collected POI point data and population density data. This analysis is still at the theoretical level, and less consideration has been given to the public's actual feelings of use. Based on the results of this theoretical analysis, the study should be followed up by field research on residents' feelings of using the facilities to improve and refine the conclusions.

(2) This study is based on the analysis of six types of public service facilities in the central districts of Nanjing, which does not focus on a single type of public service facility. In subsequent studies, more information data, such as high-precision geographic information data, should be used to explore each type of public service facilities in greater depth, to help improve the quality of public service facilities for the public. The further research results can provide theoretical reference for the future optimization of public service facilities in the central districts of Nanjing.

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