Research Article

GIS-Based Medical Resource Evaluation Method

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As one of the public service resources, medical and health care has a great guarantee for people’s healthy life and life safety and is an important part of ensuring the normal and orderly operation of urban functions. This paper takes the spatial pattern of urban medical resources in Hohhot as the research object and collects three types of urban medical resources, including clinics (health centers), specialized hospitals, and general hospitals, a total of 1300 sample points, based on GIS spatial analysis methods, using the average nearest neighbor, kernel density estimation method, standard deviation ellipse method, and accessibility measure to analyze the spatial distribution of medical resources. The results show that the medical resources in the urban area of Hohhot are all in a state of agglomeration, but due to the different functions of different types of medical resources, their distribution ranges and distribution directions also show different characteristics. Saihan District, Yuquan District in the southwest, has fewer medical facilities resources, and the distribution of accessibility of the three types of medical facilities is quite different. Therefore, the spatial balance of comprehensive medical resources in the urban area of Hohhot needs to be further improved. The results of this paper have implications for the layout of medical facilities and planning has important reference significance.

1. Introduction

As the largest developing country, China is in a stage of rapid development. With the continuous development of the social economy, people’s income level is continuously improved, living conditions are continuously improved, the demand for a better life is increasing day by day, and material life has been greatly satisfied at the same time [1–4]. The demand for various public service resources has also increased. During the “Twelfth Five-Year Plan” period, the state proposed to accelerate the establishment of a sound basic public service system, adhere to the people-oriented approach, improve the level of basic public services in cities, and strive to promote the balance of basic public services [5, 6]. Therefore, the spatial layout of public service facilities is related to people’s quality of life and social justice [7–10]. The rational and scientific allocation of medical resources is related to whether residents can enjoy the various functions and services of urban medical resources conveniently and equally and is an important foundation for realizing the harmony and unity of the three pillars of economic development, social equity, and environmental friendliness [11–13]. In the past, the evaluation methods of medical resource allocation were mostly based on traditional databases to establish information systems and quantitatively evaluate medical resource allocation capabilities by using indicators such as the balance of medical resource supply and demand, the professional skills of medical staff, and medical technicians with a population of 1,000 [14–16]. However, the traditional database lacks spatial expression ability, which limits its ability to provide decision-makers with information on the spatial distribution of medical resources and decision support [17–20].

Basic public services include basic education, social employment, social security, and medical and health care. As one of the public service resources, medical and health care has a great guarantee for people’s healthy life and life safety and is an important part of ensuring the normal and orderly operation of urban functions [21–23]. The research focus of foreign scholars on medical resources has shifted from the selection and layout of locations to the research on the fairness and accessibility of medical resources and then
gradually shifted to the spatial distribution and formation mechanism of medical resources. However, Chinese scholars have used the quantitative measurement method to study the fairness of hospital medical resource allocation from the number of hospitals and the number of doctors and have also conducted research on site selection, accessibility, and layout evaluation. At the end of 2019, a sudden outbreak of COVID-19 plunged the whole of China into a disaster. All cities responded quickly and set up designated isolation hospitals to fully guarantee the people’s medical problems. However, in areas with severe epidemics, it is still difficult to find a bed, so the spatial distribution of medical resources will directly affect the time efficiency of patient treatment when the disease occurs [24–30].

As a part of urban public service facilities, medical service facilities also occupy an important position in the city’s resource allocation. In the “Planning and Design Standards for Urban Residential Areas” (GB50180-2018), it is also mentioned that health centers and outpatient departments should be configured within the 15-minute living circle, which reflects the state’s emphasis on the layout and distribution of medical service facilities. Studying the accessibility of medical service facilities and analyzing and evaluating the distribution of urban residents, it can not only improve the convenience and fairness of residents’ access to medical service resources but also help optimize the layout of urban medical service facilities and improve medical services.

In China, many scholars have studied the accessibility and spatial distribution characteristics of medical facilities. Scholars in the field of geography mainly focus on the spatial distribution characteristics of facilities. Zeng Wen et al. took Nanjing City as an example to analyze the spatial pattern and causes of its medical service facilities. Mingji Quan took the Yanbian area as a sample, compared the spatial layout of medical facilities in the Yanbian area from 2007 to 2019, and summarized the evolution characteristics of medical facilities. Such studies are mostly theoretical explorations and lack planning advice to guide practical operations. Scholars in the field of planning focus more on evaluating the service level of facilities and exploring the spatial distribution mechanism. Taking the Hong Kong Special Administrative Region as an example, Ma Qiwei et al. analyzed the layout and functional differences of medical service facilities, analyzed their influencing factors, and put forward suggestions for the path transformation suitable for the mainland on this basis. Taking Nanjing as an example, Cao Yang et al. comprehensively evaluated the service level of medical facilities from the perspective of residents’ activities and put forward suggestions for improving the function of medical resources and optimizing the layout. Taking Hefei City as an example, Li Zao et al. analyzed the distribution pattern of its medical facilities and made a suitable aging analysis. However, from the perspective of the research scope, such research mostly focuses on a single urban or rural area and lacks thinking from the perspective of urban-rural integrated development.

Therefore, based on GIS spatial analysis methods, this paper uses the average nearest neighbor, kernel density estimation method, standard deviation ellipse method, and accessibility measure to analyze the spatial distribution of medical resources in the urban area of Hohhot. On this basis, its spatial pattern is evaluated and the deficiencies in the current model are found out.

2. Overview of the Study Area

Located in the Inner Mongolia Autonomous Region, Hohhot is the political, economic, and cultural center of the Inner Mongolia Autonomous Region approved by the State Council and an important central city in the northern border areas of my country. The city has a total of 4 municipal districts, 4 counties, and 1 flag. The city has a total area of 17,200 square kilometers, of which the built-up area is 260 square kilometers. The total population of Hohhot by the end of 2020 was 2.52 million. Among them, 439,575 people were in Xincheng District, 238,970 people were in Huimin District, 208,694 people were in Yuquan District, 563,712 people were in Saihan District, 359,107 people were in Tumutuo Banner, 199,763 people were in Tuoketuo County, 203,893 people were in Helinger County, and 139,297 people were in Qingshuihe County. There are 167,023 people in Wuchuan County. A schematic diagram of the administrative divisions and population distribution of the study area is shown in Figure 1.

The acquisition method of medical resource data involved in this study is network survey, mainly from AutoNavi electronic map, and the data vector files of each region are from the resource and environment data cloud platform. The number of medical resources collected in the urban area of Hohhot includes a total of 1,176 clinics (health centers), a total of 23 specialized hospitals, and a total of 136 general hospitals. There are 13,760 beds in health institutions, including 3,505 in Xincheng District, 4,461 in Huimin District, and 2,696 in Yuquan District. There are 33,805 technicians in medical institutions, including 6,688 in Xincheng District, 5,768 in Huimin District, and 5,489 in Yuquan District. A more intuitive distribution of medical resources is shown in Figure 2.

3. Research Method

3.1. Average Nearest Neighbor. Average Nearest Neighbor refers to the average of the closest distances between points. The spatial pattern is judged by comparing the calculated average distance of the nearest neighbor point pair with the average distance of the nearest neighbor point pair in the random distribution pattern. It can be expressed as follows:

\[ D_{ANN} = \frac{\bar{r}_E}{\bar{r}_E} = 2\sqrt{\bar{d}}, \]  
\[ \bar{r}_E = \frac{1}{2\sqrt{h/A}} = \frac{1}{2\sqrt{D}}, \]  

Formulas (1) and (2) refer to the actual nearest neighbor distance, in m, that is, the average distance between each hospital in the main urban area of Hohhot and its nearest hospital; \( \bar{r}_E \) is the theoretical nearest distance.
neighbor distance, in m, that is, the expected average distance between hospitals under random distribution mode, in m; $n$ is the total number of hospitals; $A$ is the total area of the main urban area of Hohhot City, in $m^2$; $D$ is the main urban area intrahospital point density; and $D_{ANN}$ is the nearest neighbor index. When $D_{ANN} = 1$, the hospital distribution state is random distribution; when $D_{ANN} < 1$, the hospital distribution state is an agglomerative state; and when $D_{ANN} > 1$, the hospital distribution state is discrete.

3.2. Kernel Density Method. The kernel density method is a density function used to estimate unknowns in probability theory. According to the estimation of known medical resource data points, the spatial aggregation degree of elements is analyzed. Information is effectively visualized. Its formula is as follows:

$$K(x) = \frac{1}{nd} \sum_{i=1}^{n} a \left( \frac{x - X_i}{d} \right).$$

In the formula, $a(x - X_i/d)$ is the kernel density function; $d(d > 0)$ is the distance from the hospital point to the time point $X_i$; and $K(x)$ is the estimated value of the kernel density. Using the kernel density method, the spatial distribution information of clinics (health centers), specialized hospitals, and general hospitals is visually expressed by the

Figure 1: Schematic diagram of the administrative division and population distribution of the study area.

Figure 2: Distribution map of medical resources in Hohhot.
3.3. Standard Deviation Ellipse. The standard deviation ellipse method refers to analyzing the spatial distribution characteristics of medical resources from the center, distribution range, shape, and direction of the ellipse by constructing a standard deviation ellipse. It is an important method to study the distribution direction and characteristics of spatial points, and it is also one of the most commonly used methods in spatial pattern analysis. Its formula is as follows:

$$\text{SDE}_x = \sqrt{\frac{\sum_{i=1}^{n} (x_i - \bar{x})^2}{n}},$$

$$\text{SDE}_y = \sqrt{\frac{\sum_{i=1}^{n} (y_i - \bar{y})^2}{n}}.$$  

(4)

In the formula, $x_i$ and $y_i$ represent the coordinates of medical resource data points $i$; $[\bar{x}, \bar{y}]$ represents the average center of medical resource data points; and $n$ represents the total number of study areas.

3.4. Accessibility Measure. At present, the measurement methods of the accessibility of medical service facilities are mainly divided into two categories in the macroscopic view as follows: one is the potential model and the other is the two-step mobile search method. The two models can effectively measure the accessibility of service facilities by combining relevant evaluation factors such as medical population and hospital level with different calculation methods. This paper mainly uses the GIS-based network analysis method combined with the improved potential model to measure and evaluate the accessibility of medical service facilities in the main urban area of Hohhot City.

(1) Potential Model. Mainly derived from the law of universal gravitation in physics, it was first proposed by the French scholar Lagrange and later cited by geography, adding various influencing factors such as region, grade, and economy, and deformed and developed into a potential model. Today, the potential model has developed into a classic model for studying the interaction of social and economic spaces.

$$A_i = \sum_{j=1}^{n} \frac{S_j}{D_{ij}}.$$  

(5)

Potential is the gravitational force that one object exerts on another object. In the formula, $A_i$ is the potential of facility $i$ to facility type $j$; it is the facility scale of facility $j$.

(2) Improved Potential Model. At present, for the research and development of the accessibility of urban medical facilities, factors such as the population of residential areas, the service capacity of public facilities, and the attenuation of the spatial distance between residential areas and medical service facilities are integrated into the basis of the potential model. It is also possible to set different influencing factors and other factors for different types of medical service facilities, such as service capacity, residents, city types, and resident types reachability for a more scientific explanation.

$$A_i = \sum_{j=1}^{n} \frac{S_j}{V_j D_{ij}^2},$$

$$V_j = \sum_{i=1}^{n} \frac{P_i}{D_{ij}}.$$  

(6)

(7)

In formula(7), $A_i$ is the accessibility index of a certain settlement $i$ to all medical service facilities $j$ in the area; $S_j$ is the facility scale of a medical service facility $j$. In this paper, the hospital or health center mainly includes the following: the beds represents the number of patients that can be carried, $D_{ij}$ represents the distance from settlement $i$ to the medical service facility $j$. The data in this part are mainly calculated by the OD travel table obtained from the analysis of the GIS network data. In formula (8), $V_j$ is the service capacity of facility $j$; $P_i$ is the population of a settlement $i$; and $\beta$ is represented as the travel friction coefficient. After scholars’ research on it, the value range of $\beta$ is mainly between [0.9–2.29]; $\beta$, as an influencing factor that can reflect residents’ willingness to travel, should have different values in different types of medical facilities. After comparative research, the friction coefficient $\beta$ in this paper is 1 in general hospitals. Since the single statistical accessibility is not obvious to the data, we used the dispersion standardization method to process the data on the accessibility data from residential areas to various medical service facilities in Hohhot City. Rationality analysis is carried out using the interpolation analysis diagram of the property. The standardization of dispersion is a linear transformation of the original data so that the result falls into the [0, 1] interval. The conversion function is shown in the formula, where max is the maximum value of the sample data and min is the minimum value of the sample data.

$$X_j = \frac{A_i - \min_{1 \leq j \leq n}(A_j)}{\max_{1 \leq j \leq n}(A_j) - \min_{1 \leq j \leq n}(A_j)}.$$  

(8)

In the formula, $X_j$ is the normalized value and $A_i$ is the original value.

4. Results and Analysis

4.1. Spatial Aggregation Analysis of Medical Resources. To study the spatial pattern of medical resources in the main urban area of Hohhot City, it is first necessary to determine the relationship between these medical resources and whether the spatial distribution of these medical resources is random, agglomerated, or divergent. Therefore, based on the GIS spatial analysis method and ArcGIS software, the
average nearest neighbor analysis was performed on the three types of medical resources in the main urban area of Hohhot: clinics (health centers), specialized hospitals, and general hospitals, and the nearest neighbor ratio, $Z$ score, and $P$ were calculated. The nearest neighbor ratio was used as the basis for the spatial distribution and agglomeration degree of medical resources in the main urban area of Hohhot City, and the $Z$ score and $P$ value were used to test the significance of the results. The calculation results are shown in Table 1.

4.2. Spatial Structure Analysis of Medical Resources. Through the calculation of the nearest neighbor ratio $D_{ANN}$ for the medical resources in the urban area of Hohhot, it can be seen that within this range, the spatial distribution of the three types of medical resources is in a state of aggregation. In order to observe the scope and size of each type of medical resource agglomeration more intuitively and understand its spatial structure, the nuclear density method is used to detect the state of medical resource agglomeration. The density of medical resources gradually decreases from the southwest high-density area to the Yuquan area, and its spatial pattern is mainly concentrated in the central and northeastern regions. The distribution of residents’ medical resource needs is shown in Figure 3.

4.3. Spatial Analysis of Accessibility of Medical Resources

4.3.1. Accessibility from Residential Areas to General Hospitals. The layout of general hospitals in the central urban area of Hohhot is relatively concentrated. Large general hospitals with more than 500 beds are roughly distributed at the junction of the three urban areas, and the junction is also the center of the city’s first development. There are a large number of residential areas and groups. The main road has a superior geographical location, so the accessibility from the residential area in the center to the general hospital is at the most advantageous level. In response to the trend of urban development, for Saihan District in the east, there are corresponding large-scale general hospitals, and the economic and technological development situation is relatively good. Most of the new urban areas are located in the central and northern parts of the city, so its residents have access to general hospitals in a relatively favorable position. In the southwestern region, due to development problems, the population agglomeration is relatively low, and most of the general hospitals allocated have low service capacity, resulting in the low accessibility of residents in the western and southern urban areas to general hospitals.

The accessibility standardized statistics are shown in Figure 4. The serial number on the horizontal axis in the figure represents the range of the standardization value of accessibility, and the corresponding relationship is shown in Table 2. According to the standardized statistics of accessibility, most of the values are between 0.1 and 0.6, accounting for more than 85% of the total number of residential areas, and the distribution in each value segment is relatively uniform, indicating that the number of residents from residential areas to general hospitals is relatively uniform. The accessibility is distributed in each numerical segment, and there is no obvious area where the numerical values are agglomerated.

4.3.2. Accessibility from Residential Areas to Specialist Hospitals. As the distribution of specialized hospitals is relatively scattered, the scale is small, and most of the geographical locations are at the boundary of the coverage of general hospitals, and the relatively advantageous location is at the junction junction of general hospital and specialist hospital services. Most of these types of areas have moderate-sized residential areas, dense populations, and relatively convenient transportation. In addition to the farmer’s area in the west and the recreational area in the south, the main areas where residents have insufficient accessibility to specialized hospitals also added more peripheral areas in the northeast and east. There are fewer specialized hospitals in these areas, which are affected by distance factors, resulting in reduced accessibility.

The standardized statistics of the accessibility data are shown in Figure 5. The serial number of the horizontal axis in the figure represents the range of standardized accessibility values, and the corresponding relationship is shown in Table 3. A large number of standardized data are concentrated between 0 and 0.1, accounting for more than 80% of the overall data. Most of the numerical areas in this concentration are clusters with low accessibility, indicating that the accessibility from residential areas to specialized hospitals is local.

4.3.3. Accessibility from Residential Areas to Health Centers. Since most of the health centers use their surrounding communities or residential communities as their service units, the accessibility coverage of residents in Hohhot to the health centers is relatively balanced, and the more advantageous locations are mostly around large-scale community health centers, or adjacent to. There are many areas where small clinics are concentrated. However, most of the central urban areas are within the relatively good accessibility range, and even residents in the relative leisure and underdeveloped areas in the southwest of the city can have relatively average accessibility to health centers.

The standardized statistics of accessibility data are shown in Figure 6. The serial number on the horizontal axis in the figure represents the range of standardized accessibility values, and the corresponding relationship is shown in Table 4. The standardized numerical distribution of the accessibility of residential areas to health centers is concentrated between 0 and 0.2, and there is also a relatively scattered data distribution between the values of 0 and 1. Based on the analysis in Figure 5, most of the residential areas in the data concentration area are located within the service scope of the health center, so the entire data analysis shows that the level of accessibility from the residential area to the health center is relatively balanced.
Table 1: Average nearest neighbor parameters of the spatial distribution of medical resources in Hohhot.

| Medical resources | Number of hospitals | Nearest neighbor ratio/ANN | Z score | P value |
|-------------------|---------------------|---------------------------|---------|---------|
| Clinic            | 1192                | 0.358                     | −41.16  | 0       |
| Specialist hospital | 140               | 0.422                     | −12.65  | 0       |
| General hospital  | 168                 | 0.481                     | −13.11  | 0       |

Table 2: Standardized numerical ranges for accessibility.

| Serial number | Accessibility normalized values |
|---------------|--------------------------------|
| 1             | [0.00, 0.07]                   |
| 2             | [0.07, 0.13]                   |
| 3             | [0.13, 0.20]                   |
| 4             | [0.20, 0.27]                   |
| 5             | [0.27, 0.34]                   |
| 6             | [0.34, 0.40]                   |
| 7             | [0.40, 0.47]                   |
| 8             | [0.47, 0.54]                   |
| 9             | [0.54, 0.60]                   |
| 10            | [0.60, 0.67]                   |
| 11            | [0.67, 0.74]                   |
| 12            | [0.74, 0.80]                   |
| 13            | [0.80, 0.87]                   |
| 14            | [0.87, 0.94]                   |
| 15            | [0.94, 1.01]                   |

Figure 3: Distribution map of residents’ medical resource needs.

Figure 4: Standardized statistical chart of accessibility from residential areas to hospitals.

Figure 5: Standardized statistics on accessibility from residential areas to specialized hospitals.

Table 3: Standardized value ranges for accessibility.

| Serial number | Accessibility normalized values |
|---------------|--------------------------------|
| 1             | [0.00, 0.05]                   |
| 2             | [0.05, 0.10]                   |
| 3             | [0.10, 0.14]                   |
| 4             | [0.14, 0.20]                   |
| 5             | [0.27, 0.32]                   |
| 6             | [0.36, 0.41]                   |
| 7             | [0.45, 0.50]                   |
| 8             | [0.54, 0.59]                   |
| 9             | [0.63, 0.68]                   |
| 10            | [0.72, 0.77]                   |
| 11            | [0.81, 0.86]                   |
| 12            | [0.90, 0.95]                   |

5. Conclusion

This research quantitatively studies the spatial distribution characteristics and accessibility of medical service facilities through quantitative models such as GIS spatial autocorrelation and network analysis. The three types of medical resources in the urban area of Hohhot all showed a state of...
agglomeration and distribution, showing a high degree of agglomeration. As the settlement of urban population, the main urban area has a large demand for medical resources. Therefore, the agglomeration of medical resources provides great convenience for residents to live healthy life.

The accessibility of residents in general hospitals, specialized hospitals, and health centers in the central urban area of Hohhot was analyzed using the improved potential model and variance-normalized data. From the analysis results, it can be concluded that even in the urban area of Hohhot under the measurement of the accessibility of three different types of medical facilities, the accessibility of medical service facilities in the urban center and the more developed central and northeastern urban areas is better. However, the accessibility of medical resources in less developed areas such as southwestern urban areas is relatively weak. After comprehensively comparing the accessibility of different types of medical facilities, it can be seen that the medical resources of general hospitals and specialized hospitals are complementary in some locations in the urban area. Residents in the outer circle have limited medical resources. As a community-based medical service facility, although the accessibility performance of the western and southern urban areas is slightly weaker, the health center can still provide urban residents with a relatively balanced index of medical resource accessibility. Combined with the urban development planning of Hohhot, the following optimizations can be provided:

1. Integrate medical resources in central urban areas with relatively abundant medical resources to avoid resource waste caused by high aggregation.
2. In the southwest of the city, the existing specialized hospitals can be used to appropriately increase their scale, improve their service capabilities, and enhance the willingness of surrounding residents to seek medical treatment.
3. Leisure and farmer areas in the east and north of the city can improve the scale and medical level of small general hospitals in their areas, and large-scale health centers can be established in their areas to provide basic medical services to residents.
4. The scale of the research in this paper is relatively small, and the scope is mostly the central area of the city. The research method is relatively simple. In future work, the Gini coefficient and spatial correlation analysis can also be used to make reasonable analyses, improve the analysis system, and provide more reasonable advice.

Data Availability

The dataset can be accessed upon request.

Conflicts of Interest

The author declares that there are no conflicts of interest.

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