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Study on Distribution Characteristics and Spatial Planning of Urban Medical Resources in the Context of Pandemic Prevention and Control

Taking Changchun City as An Example

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ABSTRACT:

With the normalization of pandemic prevention and control, the special planning of medical resources has become the focus of overall urban planning in China. Taking Changchun City, the capital of Jilin Province as the study area, an urban integration model based on space syntax segment model is established, with using POI, road network data and street view image data, and relying on GIS analysis platform. The density distribution and spatial structure characteristics of medical facilities at all levels are studied via multi-scale analysis method, serving as evidence for spatial planning suggestions in the future. The study shows that (1) Tertiary medical institutions mainly composed by general hospitals are highly concentrated in the very centre of downtown area, and mostly distributed around accessible roads at 15-minute vehicular radius. (2) Secondary medical institutions dominated by community medical care tend to develop in a polarized and unbalanced pattern, and require 10-minute driving distance at general level. (3) Primary medical institutions constituted by clinics share a parasitic relationship with tertiary medical institutions, and most accessible at 5-minute walking radius. At last, a hierarchical spatial planning mode of urban medical resources based on community life circles is proposed, aiming at improving pandemic prevention and control capability. The research results are consistent with the research field of practical application of space syntax, which shows that the integrated urban model can provide scientific support for effective interconnection of urban medical services at different levels, and help improve the medical ability to deal with public emergencies and service level.

KEYWORDS:

Pandemic prevention and control; Urban medical resources; Space syntax; Spatial planning

1 Introduction

The major public health emergency represented by the outbreak of coronavirus pneumonia in 2020 is a test for public service facilities. The spatial layout of public service facilities relates to people's life quality and social equity (Chaoqun et.al 2021), and the space occupied by medical resources, as a functional element that is closely linked with pandemic prevention and control and urban citizens and creates a significant impact on the urban internal spatial structure, has been widely concerned. The organizational structure and spatial layout of medical resources are changing with the urban development and the arrival of the information age. The high concentration of medical resources in the central urban area causes social problems such as urban traffic congestion and difficulties in seeking medical treatment in the periphery area. Therefore, it is necessary to carry out research and study on the distribution characteristics and spatial planning of urban medical resources in the context of the normalization of pandemic prevention and control.

In 2015, the State Council issued the *Guidance of the General Office of the State Council on Promoting the Construction of A Hierarchical Medical System* with a view to facilitating the implementation of hierarchical diagnosis and treatment, which defined the three-level medical service system with the tertiary medical institutions dominated by urban hospitals, secondary medical institutions dominated by community health service centers and primary medical institutions dominated by community clinics, and pointed out the direction for the three-level medical system planning. From central government to local authorities, and from policy to practice, specialized planning of medical resources has become the focus of urban overall planning in China. The pandemics has exposed structural problems of the medical hierarchy in certain urban areas, thus the study on the distribution characteristics and spatial planning of urban medical resources is of practical significance for the understanding of urban medical activities and urban structure. Therefore, based on the big data involving medical facility locations, traffic networks and street view images, etc., and relying on the GIS analysis platform, this paper adopts the Standard Deviational Ellipse, Kernel Density Estimation and nearest neighbor indicator analysis methods to analyze the distribution and density characteristics of medical facilities, and establishes an urban integration model based on the space syntax segment model to explore the spatial distribution of medical resources and the spatial layout of medical facilities at varied levels on the urban scale. This paper explains the internal spatial distribution pattern of medical resources from the perspective of space planning, and proposes to construct a three-level spatial layout pattern of medical resources in urban areas in accordance with community living circles and the hierarchical diagnosis and treatment system.

2 LITTERATURE REVIEW

There is a relatively complete theoretical system for the research and study on the spatial pattern of medical facilities abroad, orientated to the mutual coordination mechanism between medical resources at different levels. Michael T studied the location choice and layout pattern (Cheoljoo et.al 1988), Kontodimopoulos N studied the accessibility and fairness of medical resources (Kontodimopoulos et.al 2005), and Alexis J carried out the research on the study of the formation mechanism of spatial distribution and spatial layout of medical resources (Alexis et.al 2011).

Some other scholars also discussed the causes of the spatial distribution of medical facilities from specific perspectives, such as urban road network pattern, government governance concept, high-quality hospitals and so on (Xiaodong et.al 2021). As for the layout optimization of medical resources, William D adopted the location algorithm to study the influence of medical magnitude and distribution on the location allocation. Wang et.al studied the intensive layout of medical resources by the facility point minimization model based on the results of the accessibility analysis, and these studies mostly apply different technical analysis methods to improve the scientificity of research conclusions. Especially, the multi-scale analysis based on GIS, which provides a scientific basis for spatial layout of medical resources.

In terms of domestic research on spatial layout of medical facilities, it is more inclined towards special research on spatial allocation of medical resources at different levels. Wang Jianting et.al (Jianting et.al 2018, Shanshan et.al 2012, Ruishan et.al 2012) analyzed the spatial layout of tertiary medical institutions in central urban areas based on remote sensing images, road network information and other open-source data, and proposed the spatial allocation optimization from the perspective of spatial layout and service equilibrium; Li Shuyang, et.al (Shuyang et.al 2021, Lanlan et.al 2013, Liang et.al 2021) carried out analysis of the spatial layout of secondary medical institutions in terms of equilibrium, accessibility, applicability, etc., based on medical POI data, and proposed the spatial layout optimization of community medical care from the perspective of medical resource allocation and planning layout; Wang Zhenbao (Zhenbao et.al 2020) carried out analysis of the spatial distribution and aggregation state of primary medical institutions based on medical POI data, and proposed the optimization from the perspective of balanced layout.

To sum up, the current research on the spatial layout of medical resources is to mainly explore the supply level of medical resources at all levels through the use of different types of network data, especially the equilibrium of the allocation of secondary and tertiary medical facilities. However, the research on the cooperation model of medical resources at different levels is not adequate, highlighted by the below-average focus on medical resources below the community level. With the emergence of methods for analyzing the spatial structure of public service facilities, spatial syntax, as a new quantitative research method that can carry out multi-scale network analysis in a same model, has gradually become one of the popular analysis methods in recent years, owing to its edges of lightweight and ease of operation.

In this regard, the focus of this study is to identify the specific spatial scale of different levels of medical resources through multi-scale network analysis, and optimize the spatial structure system of urban medical resources, in the context of the pandemic prevention and control, with a view to providing spatial planning assurance for the facilitation of hierarchical diagnosis and treatment of the medical system and the sound development of life circles of urban communities, further improving the urban capacity to resist public health emergencies, and perfecting the urban spatial system of disaster prevention and enhancing the level of urban resilience.

3 DATASETS AND METHODS

3.1 Study Area

The central urban area delineated in the *Urban Overall Plan of Changchun City (2011-2020)* is taken as the study area, covering 11 administrative districts such as Chaoyang District, Kuancheng District, Lvyuan District and Nanguan District (Figure 1), with a total area of 599.9km².

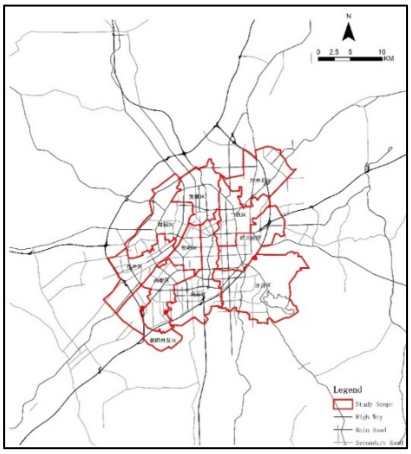


Figure 1 Schematic of Study Scope

3.2 Data Processing

(1) Point of Interest (POI) data

The data was derived from the POI collection in the urban area of Changchun City acquired by Amap in April 2020. Upon data cleaning, we first removed the networks outside the central urban area according to the address labels, selected the keywords containing "general hospital", "specialist hospital", "health center", "clinic", etc., and other keywords pertaining to medical facilities, and then checked and reclassified the subcategories with vague industry characteristics, such as "community health", "health service center' etc., so as to acquire the POI collection of medical facilities at all levels. Based on the acquired data, we further carried out spatial matching, dereplication, and deletion of network points with low degree of identification, and obtained 1868 entries of POI data of medical facilities. Finally, based on the classification of medical and health care services in Amap, and combining with the classification and designation information to reclassify the networks of the medical facilities, the revised general hospitals and specialist hospitals were reclassified as tertiary medical institutions, community hospitals and health centers as secondary medical institutions, and clinics as primary medical institutions.

(2) Road network data

The local maximum radius of 20km in the multi-scale network analysis of space syntax segment model is taken as the basis, which is then radiated by 200% as the construction range of the model, so that the analysis error caused by edge effect can be effectively avoided. The road network data in the range of north latitude 43.67-44.07N and east longitude 124.99-125.65E was intercepted from the OSM official website in 2020, mainly including railways, highways, urban expressways, national highways, provincial highways, county highways and other general roads.

(3) Area data of various medical centers

According to the longitude and latitude location information and designation information contained in each medical POI, we carried out field investigation and sampling statistics on the area of various types of medical centers, and accessed Baidu street view images to estimate building area according to the depth and width of the buildings. After confirming the feasibility of area statistics derived from Baidu street view images through area verification, we carried out quick identification and statistics of the total building area of tertiary medical institutions and secondary medical institutions and the first-floor building area of primary medical institutions. Besides, in respect of the result calculated from multiplying the number of medical centers in each street section by the area, the natural logarithm operation was used to homogenize the data.

3.3 Study Method

(1) Standard Deviational Ellipse analysis

Standard Deviational Ellipse is a classical algorithm to explore the spatial distribution direction and spread of elements, which can effectively reflect the overall spatial structure characteristics of geographical elements(Yexi et.al 2018). The main parameters include: central point, major axis and minor axis. The central point represents the central position of the whole data, the semi-major axis indicates the direction of data distribution, and the semi-minor axis identifies the data range. In this study, we select an ellipse with the standard deviation of 1 based on actual situation, to analyze and visualize 68% of the medical resources at all levels.

(2) Kernel Density Estimation

Kernel Density Estimation is based on the first law of geography. In the range of search radius, the value of density decreases with the increase of the distance from the central point, thus Kernel Density Estimation is widely used in the analysis of urban facility points (Tingting et.al 2020). Where Kernel Density Estimation is introduced into the urban spatial structure, the size of the study area is different, and the threshold of the search radius is also different (Wenhao et.al 2016). In this paper, the search radii of 500m, 1000m and 1500m are selected to test the POI data of medical facilities by the approximation method, and the search radii of 700m, 1000m and 1300m are selected for comparison. By observing the fitting degree of distribution between the search radius and the actual facility point, 1500m is finally selected as the search radius of this study. The Kernel Density Estimation diagram is superimposed with the central urban area to identify the concentration area and density distribution of medical facilities networks at all levels in the range of the central urban area. The calculation formula is:

$$f(s) = \sum_{i=1}^{n} \frac{1}{h^2} k\left(\frac{s-c_i}{h}\right) \qquad (1)$$

In formula (1): f(s) is the Kernel Density Estimation calculation function of spatial location$s$; h is the distance attenuation threshold, that is, bandwidth; n is the number of element points whose distance from the location s is less than or equal to h; ($s-c_i$) indicates the distance from the estimation point to the element point.

(3) Nearest neighbor indicator analysis

Nearest neighbor indicator (hereinafter referred to as "NNI") analysis is to derive the mean value of the nearest distance between different points. NNI can be used to determine the overall spatial aggregation characteristics of all kinds of facilities, and to measure degree of the overall aggregation and dispersion of the point distribution (Shijun et.al 2015). In this study, the NNI analysis of medical facilities at all levels is carried out to verify the results of Kernel Density Estimation. When NNI<1, the sample points show a distribution pattern of aggregation, and when NNI>1, the sample points show a distribution pattern of uniform dispersion. When NNI=1, the sample points are randomly distributed. When the formula is as follows:

$$NNI = d(NN)/d(ran) \qquad (2)$$

In formulate (2): d(NN) is the nearest distance d(ran) is the expected average nearest distance, and its value is generally:

$$d(ran) = 0.5\sqrt{A/N} \qquad (3)$$

In formula (3): N is the number of samples; A is the area of the study area.

(4) Multi-scale spatial analysis

The results of macro and micro analysis derived from quantitative expression of spatial structure by the space syntax theory were applied to the design of various scales, and even to the overall urban spatial planning (Yuyan et.al 2019). The space syntax segment model covering all the street space in the study area is established, and the multi-scale metric radius analysis method is adopted under the angular analysis pattern to extract the two kernel parameters of Angle Integration and Angle Choice in space syntax for multi-scale spatial structure analysis. Where, the Integration means the shortest topological distance from a line segment to another line segment and then to all other line segments within a certain geometric distance, which reflects the centrality and reachability of the line segment to the other line segments. Choice is the number of times that a line segment is crossed by the shortest topological path of any other two line segments within a certain geometric distance (Yanxue et.al 2020). Normalized Angular Choice (hereinafter referred to as "NACH") and Normalized Angular Integration (hereinafter referred to as "NAIN") are adopted to further eliminate the influence of the number of line segments on the analysis, so as to realize the spatial system analysis in different scales and complexity extents. Meanwhile, in order to reduce data skewness and improve the efficiency of related statistical analysis methods, considering that the natural logarithmic transformation of data is able to enable the variables to meet the application conditions of linear regression, thus four parameters (Shicheng et.al 2020), including the two parameters post natural logarithmic transformation, i.e. ln_Choice (hereinafter referred to as "lnCH") and In_Integration (hereinafter referred to as "lnIN"), are adopted to respectively carry out network analysis of 21 radii in the range of 0.4-20km and N under different gradients in combination with designated range of life circles under various travel modes and selective medical facilities at different levels according to the short-distance and long-distance medical travel radius in real life (Table 1) .

The area data of medical facilities at all levels after data homogenization are input into the street sections on the corresponding locations of the line segment model, and polynomial regression analysis is carried out with the four spatial parameters. The radius with greater correlation creates a greater influence on the spatial structure of medical facilities, and the method can truly reflect the distribution potential of medical resources in a certain range. The radius can also be used as a basis for the spatial planning of medical facilities.

Table 1 Summary Table for Radius Selection of Multi-scale Network Analysis

<table>
<tr><th>Network analysis</th><th colspan="2">Living circle</th><th>Radius selection</th><th>Short-distance</th><th>Long-distance</th><th>Medical needs</th></tr>
<tr><td rowspan="11">Multi-scale network analysis (metric distance)</td><td rowspan="3">Walk</td><td>5min</td><td>200, 400</td><td rowspan="2">Primary</td><td rowspan="4">Primary</td><td rowspan="11">Actual medical travel (the level of medical facilities)</td></tr>
<tr><td>10min</td><td>600, 800</td></tr>
<tr><td>15min</td><td>1200, 1500</td><td rowspan="2">Secondary</td></tr>
<tr><td rowspan="3">Cycling</td><td>5min</td><td>1600</td></tr>
<tr><td>10min</td><td>3200</td><td rowspan="4">Tertiary</td><td rowspan="4">Secondary</td></tr>
<tr><td>15min</td><td>4800</td></tr>
<tr><td rowspan="5">Motorized travel</td><td>5min</td><td>2400, 3000</td></tr>
<tr><td>10min</td><td>3600, 4800,</td></tr>
<tr><td>15min</td><td>7200, 8000,</td><td rowspan="2">/</td><td rowspan="2">Tertiary</td></tr>
<tr><td rowspan="2">>15min</td><td>10000, 15000</td></tr>
<tr><td>20000, N</td><td>/</td><td>/</td></tr>
</table>

4 RESULTS

4.1 Distribution Characteristics of Medical Resources

(1) Mono-center centralized development of tertiary medical institutions

The coverage of the ellipse is the old center of urban area, where 70% of the tertiary medical institutions are mainly distributed in the old urban area, and the remaining 30% are mainly distributed in the south of the city. According to the major axis of the ellipse, no obvious directionality and potential development orientation are observed for the distribution of large-scale medical resources. The density distribution of tertiary medical institutions is in a pattern of mono-center centralized development, in contrast to the surrounding new development areas where there is a lack of service capacity of medical resources (Figure 2a). Medical resources are mainly distributed in the urban space of the intersection of the three administrative districts, i.e. north of Chaoyang District, north of Nanguan District and south of Erdao District, and are relatively less distributed in the peripheral new development areas of the city.

According to the NNI analysis and verification, the value of NNI is 0.885 < 1 (Table 2), which indicates a significant aggregated distribution pattern, and confirms the mono-center centralized development of tertiary medical institutions in terms of distribution.

(2) Dual-center polarized development of secondary medical institutions

The overall spatial distribution pattern of medium-scale medical facilities shows the characteristics of spatial aggregation along the major axis in the direction of "southwest-northeast" and has the potential to further develop along the direction, which is consistent with the future development orientation of the city and the development space of the new area. The density distribution of medium-scale medical facilities shows the pattern of dual-center polarized development, and there is a lack of linkage between the new and old areas in terms of development governance (Figure 2b). Medical resources are mainly distributed in the urban space in the south of Chaoyang District and the north of Nanguan District. The NNI value is 0.756 < 1 (Table 2), which shows a significant aggregated distribution pattern, and confirms the dual-center polarized development of secondary medical institutions in terms of distribution.

(3) Multi-center differentiated development of primary medical institutions

The spatial distribution pattern of primary medical institutions is generally along the major axis space in the direction of "southwest-northeast", and the center is more inclined to the space in the north. The density distribution of primary medical institutions shows the pattern of multi-center differentiated development, which shares an obvious parasitic relationship with tertiary medical institutions, and there is a structural imbalance in terms of cross-level linkage. (Figure 2c). Medical resources are mainly concentrated in the central-north of urban space of the intersection of the middle of Lvyuan District, north of Chaoyang District, north of Nanguan District and north of Erdao District, and are relatively less distributed in the northeast and south.

The NNI value is 0.480 < 1 (Table 2), which shows a significant aggregated distribution pattern, and confirms the multi-center differentiated development of primary medical institutions in terms of distribution.

To sum up, (1) In terms of the center of distribution, the medical facilities at all levels are concentrated in the old urban area in the pattern of significant spatial aggregation, which shows that there is a problem of resource allocation imbalance at all levels of the medical facilities. Tertiary medical institutions, secondary medical institutions and primary medical institutions are distributed in the pattern of mono-center, dual-center, and multi-center aggregation respectively, among which the degree of spatial aggregation of primary medical institutions with commercial nature is the strongest, with fierce competition and serious spatial dislocation. (2) The spatial distribution of secondary medical institutions and primary medical institutions tends to go along with the direction of "southwest-northeast", and there is no obvious directional tendency in the distribution of tertiary medical institutions, thus it can be seen that the development orientation of the city has created a major impact on the distribution of secondary medical institutions and primary medical institutions, and has little impact on tertiary medical institutions featuring high construction costs.

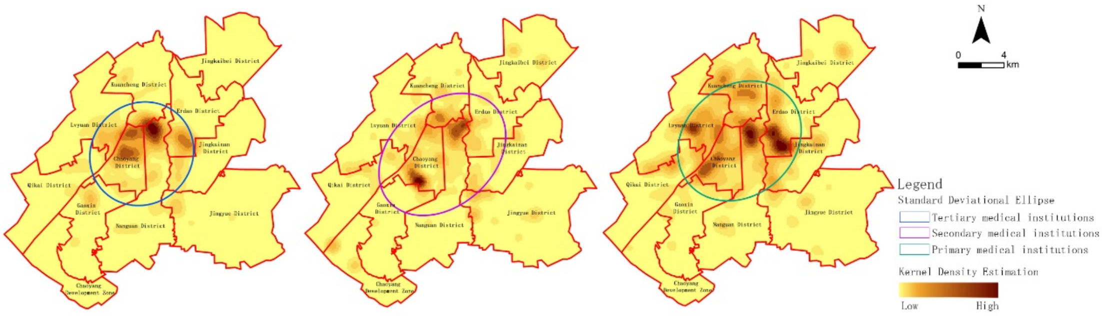


Figure 2 Schematic diagram of superposition analysis of Kernel Density Estimation and Standard Deviational Ellipse for Tertiary medical institutions (a), Secondary medical institutions (b) and Primary medical institutions (c)

Table 2 Statistical Table of Analytical Parameters of the Average Nearest Neighbor Distance for Medical Service Facilities at All Levels

Type	Tertiary medical institutions	Secondary medical institutions	Primary medical institutions
NNI	0.885	0.756	0.480
Score of Z	-1.861	-5.267	-32.449
Value of P	<0.1	<0.01	<0.01
Confidence level	90%	99%	99%

4.2 Spatial Structure of Medical Resources

(1) Spatial Structure Characteristics of Tertiary Medical Institutions

According to the variation of correlation between the space syntax parameters under the four categories of radii, and the total building area of tertiary medical institutions in each street section post data homogenization, the space syntax parameters with the highest correlation corresponding to each category of radii are selected as the suitable radii (Table 3), as the independent variables of the polynomial regression analysis. And, in order to eliminate the autocorrelation error of independent variables in the regression analysis, after the correlation analysis of the four groups of independent variables is complete, the group of space syntax parameters with the lowest correlation is selected as the optimal radii to carry out a binary cubic polynomial regression analysis with the total building area of the tertiary medical institutions in each street section post data homogenization (Figure 3).

Table 3 Statistical Table of the Space Syntax Parameter Correlation of Four Suitable Radii for Tertiary Medical Institutions

Spatial parameters	NACH (R15000m)	NAIN (R5000m)	lnCH (R1000m)	lnIN (R2400m)
NACH (R15000m)	1	0.656	0.988	0.440
NAIN (R5000m)	0.656	1	0.744	0.854
lnCH (R1000m)	0.988	0.774	1	0.580
lnIN (R2400m)	0.440	0.854	0.580	1

The functional relation is:

$$y = 0.0006 + 2.1196x_1^3 - 0.0236x_2^3 + 2.9716x_1^2 + 0.0699x_2^2$$
$$-1.2033x_1^2x_2 + 0.2443x_2^2x_1 - 0.8842x_1 + 1.5368x_2 - 0.771x_1x_2 \quad (4)$$

In formula (4), y is the result of logarithmic homogenization of the total building area of tertiary medical institutions in each street section. x_1 is the result of NACH under the radius of 15000m. x_2 is the result of Integration post logarithmic homogenization under the radius of 2400m (Table 4).

Table 4 Model Parameter Test

Model	NACH (R15000m)	lnIN (R2400m)	Regression equation
T	17.447	109.619	—
F	—	—	12159.82
R^2	—	—	0.786
Significance	0.000	0.000	0.000
Variance	—	—	0.082

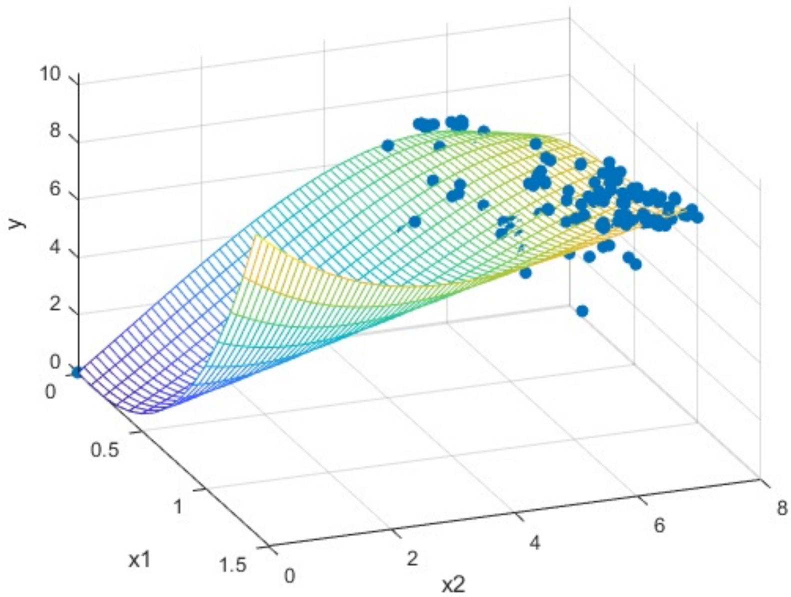
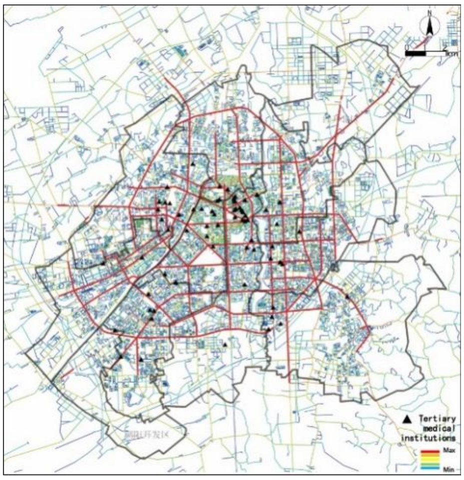


Figure 3 Surface Fitting Chart for Tertiary Medical Facilities and Spatial Parameters

The results show that: (1) The spatial structure of tertiary medical institutions is relatively obviously affected by the Choice parameter under the radius of 15000m, with an obvious linear distribution structure along urban trunk roads and high-grade traffic roads (Figure 4a). Secondly, it is also most obviously affected by the Integration parameter under the radius of 2400m, with an obvious central distribution structure in the old urban areas, especially in the neighbor space of the south of Chaoyang District and the south of Nanguan District (Figure 4b). (2) The optimal radius of Choice is 15000m, which is much larger than the distance of 15-minute motorized commuting circles, and 2400m corresponding to the distance of 5-minute motorized commuting circles, mainly due to the overconcentration of tertiary medical institutions in the central urban area of the city and its superposition with the high accessibility space under the Integration of the 5-minute motorized travel scale, this not only creates a burden on the daily traffic commuting in the central urban area, but also leads to the imbalance of the supply and demand of medical services across the new and old urban areas resulted from the binary spatial distribution, which demonstrates that tertiary medical institutions are operating not only meet the medical needs of the urban areas, but also provide services to the surrounding prefectures.



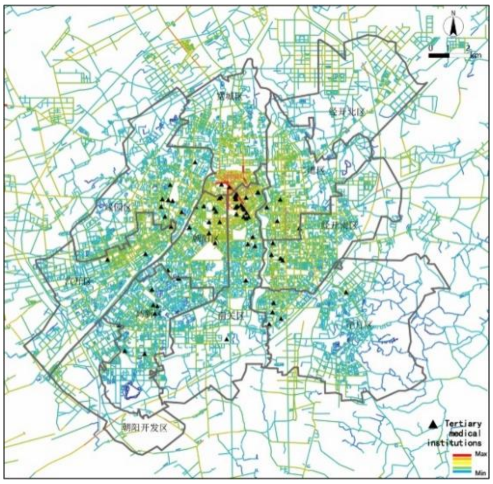


Figure 4 (a) Analysis Diagram for the Superposition of 15000m NACH Spatial Structure and Tertiary medical institutions

Figure 4 (b) Analysis Diagram for the Superposition of 2400m Integration Spatial Structure Post Logarithmic Homogenization and Tertiary medical institutions

(2) Spatial Structure Characteristics of Secondary Medical Institutions

According to the variation of correlation between the space syntax parameters under the four categories of radii and the total building area of secondary medical institutions in each street section post data homogenization, same as above, and after the suitable radii are determined (Table 5), the group of space syntax parameters with the lowest autocorrelation is selected as the optimal radii to carry out binary cubic polynomial regression analysis with the total building area of the secondary medical institutions in each street section post data homogenization (Figure 5).

Table 5 Statistical Table of the Space Syntax Parameter Correlation of Four Suitable Radii for Secondary Medical Institutions

Spatial parameters	NACH (R400m)	NAIN (R6000m)	lnCH (R2400m)	lnCH (R2400m)
NACH (R400m)	1	0.454	0.530	0.688
NAIN (R6000m)	0.454	1	0.726	0.715
lnCH (R2400m)	0.530	0.726	1	0.594
lnCH (R2400m)	0.688	0.715	0.594	1

The functional relation is:

$$y = 0.0001 + 6.3799x_1^3 + 5.3102x_2^3 - 6.1494x_1^2 - 15.7064x_2^2$$
$$-3.6142x_1^2x_2 - 2.7376x_2^2x_1 - 4.5901x_1 + 14.9064x_2 + 11.0922x_1x_2 \quad (5)$$

In formula (5), y is the result of the total building area of secondary medical institutions in each street section post logarithmic homogenization. x_1 is the result of NACH under the radius of 400m. x_2 is the result of NAIN under the radius of 6000m (Table 5).

Table 6 Model Parameter Test

Model	NACH (R400m)	NAIN (R6000m)	Regression equation
T	9.600	69.661	—
F	—	—	7122.132
R^2	—	—	0.832
Significance	0.000	0.000	0.000
Variance	—	—	0.051

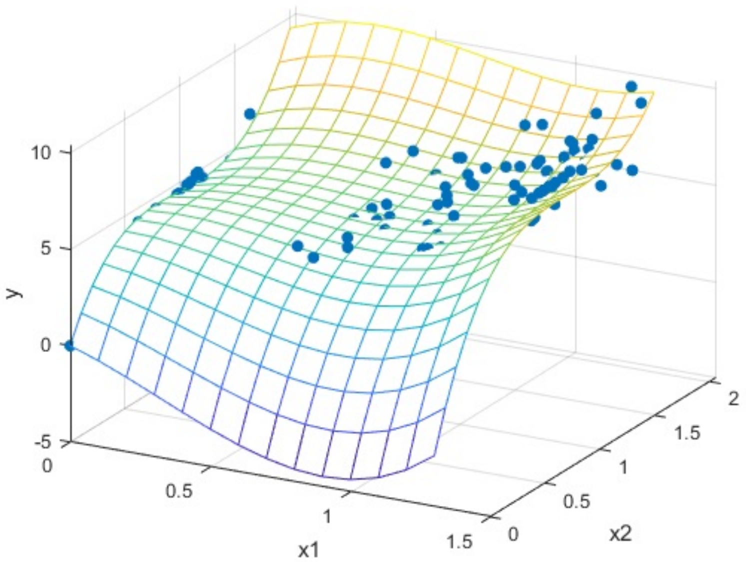


Figure 5 Surface Fitting Chart for Secondary Medical Facilities and Spatial Parameters

The results show that: (1) The spatial structure of secondary medical institutions is most obviously affected by the Integration parameter under the radius of 6000m, with an obvious central distribution structure in the People's Square and its surrounding space (Figure 6a). Secondly, it is also relatively affected by the Choice parameter under the radius of 400m, with an obvious dot-type distribution structure along the community living streets (Figure 6b). (2) The optimal radius of Integration is 6000m, corresponding to the 10-minute motorized commuting distance, and the optimal radius of Choice is 400m, corresponding to the 5-minute walking distance. The dual-center polarized spatial distribution of secondary medical institutions can't meet the medical needs of the service chain of "Treatment - Rehabilitation - Long-term Medical Care", and its spatial structure is affected by the 10-minute motorized commuting distance, which aggravates the transfer of medical pressure to the large-scale medical facilities and can't meet the medical needs in the 10-minute community living circle under green travel governance. Thus, it can be seen that the secondary medical institutions mainly provide medical services for the administrative districts of the central city.

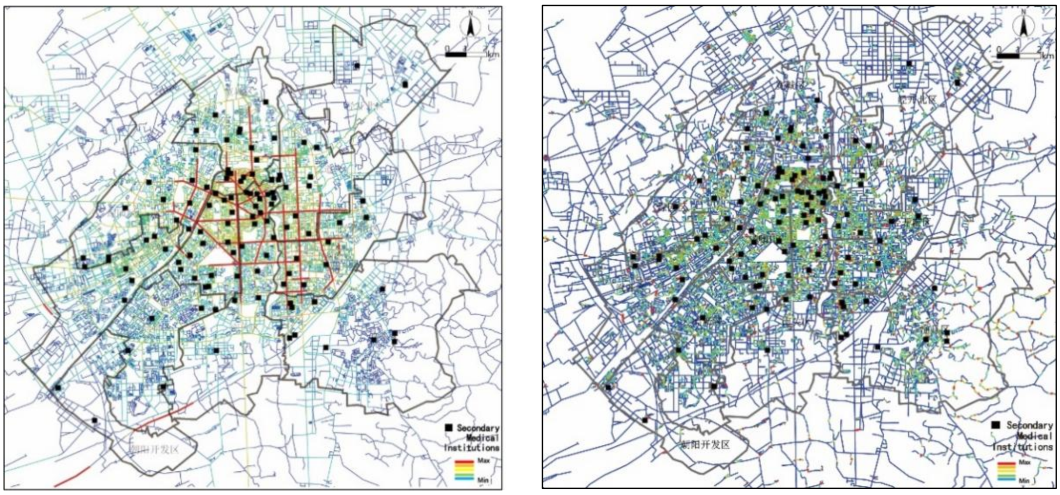


Figure 6 (a) Analysis Diagram for the Superposition of 6000m NAIN Spatial Structure and Secondary Medical Institutions

Figure 6 (b) Analysis Diagram for the Superposition of 400m NACH Spatial Structure and Secondary Medical Institutions

(3) Spatial Structural Characteristics of Primary Medical Institutions

According to the variation of correlation between the space syntax parameters under the four categories of radii and the first-floor building area of primary medical institutions post standardization, same as above, and after the suitable radii are determined (Table 7), the group of space syntax parameters with the lowest autocorrelation is selected as the optimal radii to carry out binary cubic polynomial regression analysis with the first-floor building area of the primary medical institutions post standardization (Figure 7).

Table 7 Statistical Table of the Space Syntax Parameter Correlation of Four Suitable Radii for Primary Medical Institutions

Spatial parameters	NACH (R400m)	NAIN (R400m)	lnCH (R400m)	lnIN (R400m)
NACH (R400m)	1	0.314	0.874	0.679
NAIN (R400m)	0.314	1	0.282	0.539
lnCH (R400m)	0.874	0.282	1	0.751
lnIN (R400m)	0.679	0.539	0.751	1

The functional relation is:

$$y = 0.0005 + 0.3798x_1^3 + 0.0073x_2^3 - 2.4803x_1^2 - 0.0487x_2^2$$
$$+0.3793x_1^2x_2 - 0.0266x_2^2x_1 + 4.0635x_1 + 0.9216x_2 - 0.7504x_1x_2 \qquad (6)$$

In formula (6), *y* is the result of the first-floor building area of primary medical institutions in each street section post logarithmic homogenization; x_1 is the result of NAIN under the radius of 400m; x_2 is the result of Choice post logarithmic homogenization under the radius of 400m (Table 8).

Table 8 Model Parameter Test

Model	NAIN (R400m)	lnCH (R400m)	Regression equation
T	3.918	28.272	—

F	—	—	119.971
R^2	—	—	0.601
Significance	0.001	0.000	0.001
Variance	—	—	0.154

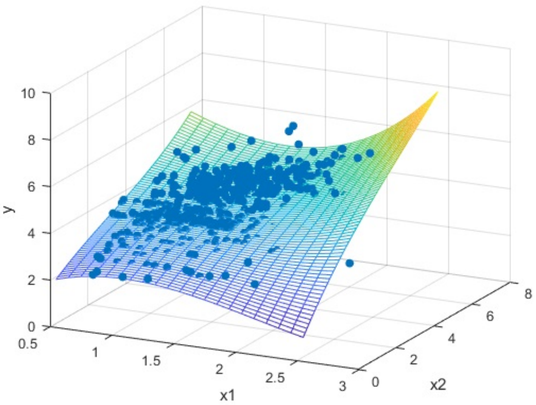
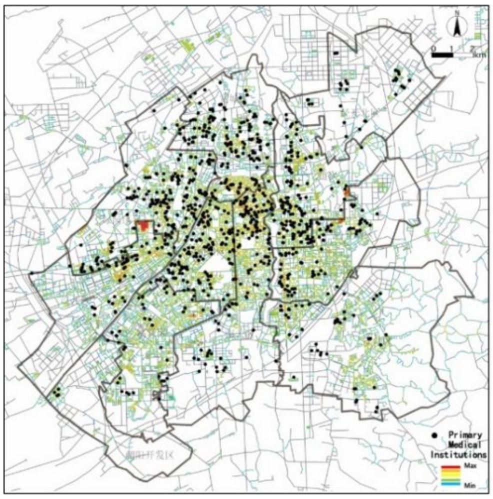


Figure 7 Surface Fitting Chart for Primary Medical Facilities and Spatial Parameters

The results show that: (1) The spatial structure of primary medical institutions is most obviously affected by the Choice parameter under the radius of 400m, with an obvious linear distribution structure along the living street (Figure 8a). Secondly, it is also relatively affected by the Integration parameter under the radius of 400m, with an obvious central distribution structure in the middle and north of the city (Figure 8b). (2) The optimal radius of Choice is 400m and the optimal radius of Integration is also 400m, both of which correspond to the 5-minute walking commuting distance. The The multi-center aggregated spatial distribution causes excessive competition and waste of medical resources. Compared with tertiary medical institutions and secondary medical institutions, primary medical institutions represented by clinics with commercial nature can meet the basic medical needs of the 5-minute community living circle. Thus, it can be seen that primary medical institutions mainly provide medical services for the communities.



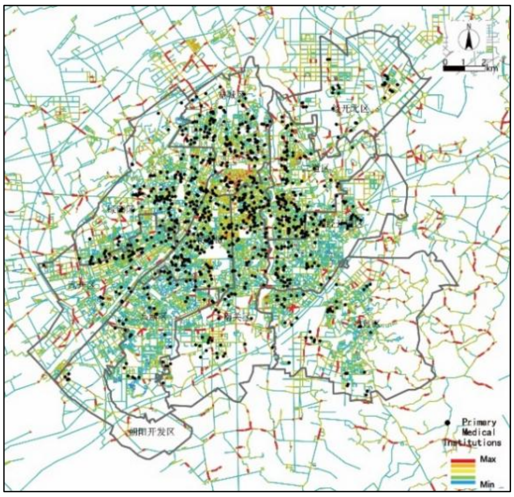


Figure 8 (a) Analysis Diagram for the Superposition of 400m Choice Spatial Structure post Logarithmic Homogenization and Primary Medical Institutions

Figure 8 (b) Analysis Diagram for the Superposition of 400m NAIN Spatial Structure and Primary Medical Institutions

5 CONCLUSIONS

The optimal radius for spatial distribution of medical facilities at different levels shall be determined by multi-scale network analysis. In the context of vigorous promotion of hierarchical diagnosis and treatment by the government, communities are not only the primary battleground of pandemic prevention and control and virus tracking, but also the key link in the implementation of hierarchical diagnosis and treatment. For a long time in the future, communities will be required to properly carry out seamless switching between normalized and wartime pandemic prevention and control. With a view to improving the service efficiency of medical resources and the ability to resist major risks, this paper proposes to optimize the medical service network and the spatial structural system of urban medical resources and provide a new pattern of spatial layout of medical resources at all levels in view of the inherent spatial structural logic in the unique three-level medical health service system in China, with the 5-, 10- and 15-minute living circles defined in the *2018 Urban Residential Area Planning and Design Standards* (hereinafter referred to as the "Standard") as the basis.

5.1 Circle-based spatial allocation pattern of tertiary medical institutions

Due to the excessive aggregation of tertiary medical institutions in the urban center and the actual service range far beyond the standard range, it shows the spatial structure dependence on the 5-minute motorized travel distance and the commuting circles of more than 15-minute motorized travel. Therefore, in terms of the spatial allocation, it is suggested to take the tertiary medical institutions as the center and rely on the fast and accessible urban trunk network. In this paper, we propose to construct a circle-based spatial allocation pattern of tertiary medical institutions based on 15-minute living circles,, through the multi-mode travel orientation of "Walk + Cycling + Public Transport", so as to reduce the spatial dependence of large-scale medical facilities on the motorized travel scale, and promote the effective implementation of classified treatment for acute and chronic diseases and up-down linkage (Figure 9a). (1) Appropriately allocate certain tertiary medical institutions from the aggregated medical centers to the surrounding space established with favorable public transport sites and convenient connections, and select adjacent urban trunk roads, high-grade traffic roads and other convenient transport locations for the areas with deficient medical facilities, to build a "Public Transport Accessibility Circle" of tertiary medical facilities based on the 5-minute public transport radius, so as to realize the interconnection between secondary and tertiary medical institutions in terms of space and resources, promote downward settlement of high-quality medical resources, and improve the prevention and control capacity of secondary medical institutions against chronic diseases. (2) Use 15-minute walk circles to connect with 5-minute public transport circles and 10-minute cycling circles, so as to respectively build the "Walk + Public Transport Accessibility Circle" and "Cycling Accessibility Circle" for tertiary medical institutions, realize the up-down linkage of primary, secondary and tertiary medical institutions, and eventually guide the position settled of large-scale medical facilities in the 5-minute public transport coverage. (3) In the context of pandemic prevention and control, tertiary medical institutions shall, in addition to meeting the daily requirements of medical care and treatment, act positively to serve as standby resource points and reserve certain flexible space to meet the urgent medical assistance requirements upon abrupt occurrence of major public incidents and the dynamic medical service requirements of residents in the living circles. In doing so, the coverage of medical service requirements in the 15-minute living circles can be consolidated by local tertiary medical institutions, which will also be able to provide medical services to surrounding cities and counties.

5.2 Compatible spatial allocation pattern of secondary medical institutions

The secondary medical institutions demonstrate a stronger spatial dependence on the spatial structure of the 10-minute motorized travel distance, which is not only unable to give full play to the medical characteristics of two-way referral, but also further transfer the stress of medical diagnosis and treatment to the tertiary medical institutions. Therefore, in terms of the spatial allocation, it is suggested to take the secondary medical institutions as the center and rely on the urban secondary trunk network and branch network. In this paper, we propose to construct a compatible spatial allocation pattern of secondary medical institutions based on 10-minute living circles, through travel orientation of "Walk + Cycling", so as to promote two-way medical referral, and meet the medical service requirements of residents in the service chain of "Treatment - Rehabilitation - Long-term Medical Care" (Figure 9b). (1) Based on the 15-minute circle-based spatial pattern of tertiary medical institutions, diverge those primary medical institutions which are aggregated and yet deficient in medical strength and convert them into secondary medical institutions, and convert certain secondary medical institutions with solid medical strength into tertiary medical institutions, so as to fill up the vacancy of secondary medical institutions and relieve the medical service pressure of tertiary medical institutions, and improve the medial supply compatibility of secondary medical institutions in two-way medical referral. (2) Upon new development of secondary medical facilities, select adjacent public transport sites and community living streets and carry out reasonable locating of grouping centers on the basis of 5-minute public transport accessibility to tertiary medical institutions, 10-minute walk accessibility to primary and secondary medical institutions, and 5-minute cycling accessibility to medical service of secondary medical institutions in any surrounding grouping space, so as to improve the compatibility of spatial accessibility of secondary medical institutions in two-way referral. (3) In the context of pandemic prevention and control, appointed referral and on-site inquiry offered by secondary medical institutions lead to more workloads of medical service, which is conductive to drawing high-quality medical resources to settle down and form a forward loop. In the normalized pandemic prevention and control situation, it is suggested that the medical service mode of "Appointment + Online and Offline Combination" should be further promoted to enhance the service stickiness of secondary medical institutions, promote the forward loop, and improve the service mode compatibility of secondary medical institutions in two-way referral.

5.3 Intensive spatial allocation pattern of primary medical institutions

The primary medical institutions demonstrate a stronger dependence on the urban spatial structure of the 5-minute walk, which is basically in line with the medical needs of the community life circles. However, the excessive aggregation of primary medical institutions leads to a waste of medical resources and lower economic benefits. Therefore, in terms of spatial allocation, it is suggested to take the primary medical institutions as the center, and rely on the community-level living road network. In this paper, we propose to construct an intensive spatial allocation pattern of primary medical institutions based on 5-minute living circles, through the enhancement on walk travel orientation, so as to improve the convenience of neighborhood diagnosis service and primary-level initial diagnosis proportion of primary medical institutions in the hierarchical diagnosis and treatment system (Figure

9c). (1) In areas with an excessive layout of primary medical institutions, convert certain primary medical institutions into secondary medical institutions, so as to avoid the waste of medical resources resulting from excessive competition of primary institutions driven by the market. (2) Upon new creation of primary medical institutions, carry out reasonable location along the accessible living streets, with the 5-minute walk accessibility coverage as the center and the current layout of secondary medical institutions as the basis, so as to form an intensive layout of "Population-orientated Aggregation ", directly meet the daily medical service requirements of residents, and increase the primary-level initial diagnosis proportion. (3) In the context of pandemic prevention and control, the medical capacity of secondary medical institutions is substantially diverged into pandemic preliminary screening and referral, and certain daily medical service demand is transferred to primary medical institutions, which mobilizes more physicians to open up individual medical institutions to provide diversified primary-level medical services and increase the primary-level initial diagnosis proportion. In the normalized pandemic prevention and control situation, it is suggested that social medical establishment should be vigorously promoted, admission approval procedures for individual medical services should be simplified, and qualified physicians should be encouraged to open up individual clinics, with a view to offering medical services to the grass-roots on a local and handy basis.

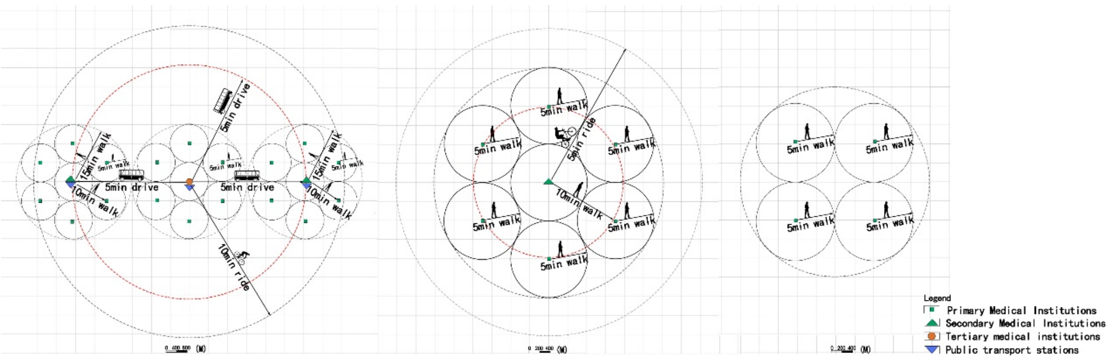


Figure 9 Schematic Diagram of Spatial Configuration of Tertiary medical institutions (a), Secondary Medical Institutions (b) and Primary Medical Institutions (c)

In conclusion, based on the hierarchical diagnosis and treatment system and mechanism of regular pandemic prevention and control, the medical administration authority may, when formulating specialized planning, carry out linkage adjustment of elements, enhance coordinated configuration of the spatial elements of the three-tier medical network, realize refined planning governance and resource allocation for the spatial aggregation of the elements of medical facilities, reduce the gap between the old and new urban areas in terms of resource occupation, and promote the gradual improvement of the hierarchical diagnosis and treatment mode in terms of initial diagnosis at the foundation layer, two-way medical referral, classified treatment for acute and chronic diseases, and up-down linkage, in accordance with the actual situation and management mechanism.

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