Assessment of the supply/demand balance of medical resources in Beijing from the perspective of hierarchical diagnosis and treatment

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Abstract

Considering the United Nations' Sustainable Development Goals (SDGs) and the need for a balanced spatial distribution of urban medical resources capable of perspective of hierarchical diagnosis and treatment, *i.e.* providing continuous and accessible medical services during potential public health emergencies, we assessed accessibility and service capacity of the three hospital levels in Beijing. Using geographical information systems (GIS) and the two-step floating catchment area method with the street as research unit, we found that there is an over-supply of medical resources in the centre of the city with weaker support in the peripheral areas as manifested by less supply in relation to popular demand of medical services. The spatial distribution of hospitals at all levels and their resources was found to be uneven: 82.4% of the residents can reach a tertiary hospital (a hospital offering advanced specialized medical and health services to multiple regions) within a 15-minute drive; 50.6% can reach a secondary hospital (a hospital offering comprehensive medical and health services to various communities) within a 10-minute drive; and 77.6% can reach a primary hospital (a hospital directly delivering prevention, medical treatment, healthcare, and rehabilitation services to the community of a certain population) within a 15-minute walk. It was noted that the supply/demand balance of medical resources in the tertiary hospitals decreases from the centre to the periphery, while the secondary hospitals show a dual-centre pattern and the primary hospitals a more uneven distribution, with oversupply in the East and the opposite in the Centre. The results of the study provide supplementary decision support for improving the hierarchical diagnosis and treatment system and accelerate the overall deployment of medical resources.

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Introduction

The allocation and layout of urban medical resources are important components urban, public service facilities and their spatial distribution is related to citizen health and social equity (Liang & Yang, 2021). In 2015, the United Nations proposed 17 Sustainable Development Goals (SDGs) with 169 targets to achieve global sustainable development by 2030 (https://sdgs.un.org/goals). Among the 13 targets of SDG 3.8 the need to achieve universal health coverage is emphasized. This requires allocation of medical resources to be fully covered and balanced with respect to supply and demand. As a consequence, the assessment and monitoring of the implementation of SDG 3.8 is a regional, necessary task for the implementation of the 2030 SDG Agenda, and an inherent requirement for regional sustainable development.

Epidemics or pandemics, such as influenza A/H1N1, COVID-19, have caused serious loss of health and sustainable development. Outbreaks of infectious diseases pose a serious challenge to the health system and society as a whole as they can disrupt the delivery of essential health services, e.g., China, the world's most populous country, experienced an difficult impact due to the re-emergence of COVID-19 in December 2022. To cope with such situations, hospitals need to adopt effective strategies to manage the supply/demand ratio of resources to effectively prevent congestion and assure that continuous and accessible medical services are provided (Yip *et al.*, 2020). Beijing Municipality has long been striving to promote a balanced distribution of high-quality medical resources, with coverage of basic resources as evidenced in its "14th Five-Year Plan" for 2021-2025.

With regard to health, spatial accessibility reflects the degree of convenience in finding medical care. It is an important research perspective used to evaluate the rationality of the spatial allocation of public service facilities, as well as an important indicator to measure whether the result is balanced (Liu *et al.*, 2007). For example, in the United States (US) Bennet *et al.* (1981) conducted a study to predict the location and number of medical facilities based on the population distribution of Lansing, Michigan, while Luo and Wang (2003) evaluated the spatial accessibility of public medical resources in Chicago area by using the two-step floating catchment area (2SFCA) method, originally proposed by Radke and Mu (2000) and further improved by Luo and Wang (2003). McGrail and Humphreys (2009) improved this approach by introducing a distance decay function and variable effective service radii. Based on the traditional nuclear density analysis method, Schuurman *et al.* (2010) introduced the gravity model to improve the accessibility of medical institutions in Nova Scotia, Canada. Wang and Tang (2013) studied the employment situation and accessibility value of primary hospitals in the US State of Ohio, from the perspective of the supply/demand balance, and compared the differences in their distribution between downtown and suburban areas.

In addition to accessibility, scholars also reflect on the balance and equity of medical resources through other methods and perspectives. For example, Ruiz *et al.* (2013) used the concentration index to evaluate the equity of the Colombian healthcare system in terms of four dimensions: population health status, quality of health services, health service utilization and health care expenditures. Horev *et al.* (2004) used the Gini coefficient to study the distribution of health care resources in the US by combining various influencing factors, such as the number of physicians, the number of beds per capita, geographic location, and income disparity. Aftser the concept of accessibility was proposed, Wang (2006) studied the accessibility of various residential areas to medical facilities in Shanghai through the nearest proximity method based on population data. Cheng and Lian (2018a) used the hospital grade scale factor and population scale factor to study the spatial distribution of hospitals in Shanghai's Yangpu District, while Li *et al.* (2018) included hospital quality level, number of physicians and number of beds in an evaluation system exploring the balance of medical resource allocation in Xiangtan from the perspective of the hospital competition effect. Zhao *et al.* (2018) used spatial analysis and statistical analysis to construct the minimum travel time and spatial accessibility index to evaluate the spatial differentiation characteristics of the accessibility of medical facilities in Beijing. In 2017, taking the street as the basic unit and considering ground and rail transit as two travel modes, Meng and Zhang (2017) used the 2SFCA method to analyze the accessibility and spatial characteristics of secondary and tertiary hospitals in Beijing. Our investigation planned to analyze the current supply and demand situation of medical resources in the central urban area of Beijing from the perspectives of hospital spatial distribution pattern and their service capacity, *i.e.* resource allocation. We used the street scale as evaluation unit to grade the access to care and further investigate the supply/demand balance by taking into account the population size and number of hospital beds, which helps optimize the layout and allocation of medical resources.

Materials and Methods

The 2SFCA method and geographical information systems (GIS) assist service area analysis, which refers to the determination of the coverage range of a facility based on the distance or time required to reach its location. By analysing the population covered by each service area, the service capacity of the facility was determined under different travel demands. This approach was used to conduct an assessment of the spatial layout, accessibility and service capacity of three levels of hospitals in Beijing: i) The tertiary hospital operates at the provincial or national level. It provides advanced specialized medical and health services to multiple regions while also conducts higher education and scientific research; ii) The secondary hospital operates at the district level. It provides comprehensive health services and is able to conduct research on a regional basis; iii) The primary hospital is the most common and operates at the township level. It directly provides minimal health care and rehabilitation service to a specific population within the community.

Study area

Six central urban districts in Beijing, namely Dongcheng, Xicheng, Haidian, Chaoyang, Fengtai and Shijingshan, were taken as study area. These districts cover about 1,381 km^2, include 133 streets and have a resident population of 10,989,000 according to the latest census. The distribution of hospitals at all levels in this area is shown in Figure 1.

Data source and pre-processing

We used basic geographic information data for 2020 including: i) road network data from Open Street Map (OSM) (https://www.openstreetmap.org); ii) administrative districts and streets data from National Center for Basic Geographic Information; iii) hospital data (names, coordinates, categories and other information) from the Gaode Map platform (https://lbs.amap.com/api/webservice/summary/) based on the Compendium of Statistics on Health Work in Beijing and data from the Beijing Health and Health Big Data and Policy Research Center (http://www.phic.org.cn/), there are 102 tertiary hospitals (44 of which being Grade-A) (the highest level of hospital in China's healthcare system), 107 secondary and 767 primary ones - 976

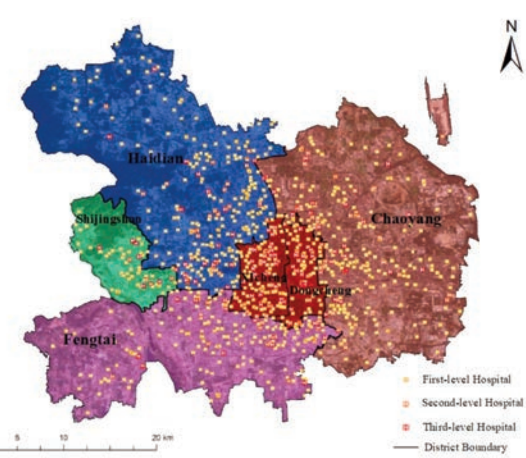

Figure 1. Overview of the study area. The upper right of the study area is Capital Airport Street, which is under Chaoyang District.

hospitals in all; and iv) population distribution data (from Worldpop, a 100-m^2 raster-based population dataset) covering Beijing. The above data were transformed by the projection coordinate system WGS_1984_UTM_Zone_50N before use. The topology of the road network data was checked to ensure integrity and accuracy.

Population data

Our work was based on the following data for the year 2020: i) the resident population (from the Bulletin of the Seventh National Population Census of Beijing, no. 2; ii) the number of physicians (from the Compendium of statistics on health work in Beijing); iii) the number of hospital beds (through data crawling on 39 medical and biological information websites, such as Health.com, Clove Garden etc.). All information was geo-aligned and linked in Excel tables with geospatial data such as hospital administrative borders and surrounding streets.

Research design

To investigate the supply/demand balance and overall distribution characteristics of the three levels of hospitals in the study area, we used the street scale as unit utilizing 2SFCA and service area analysis to evaluate the spatial distribution, accessibility and service capacity. The overall technical flow chart is shown in Figure 2. Nuclear density analysis and service area analysis were used to study the spatial layout, service scope and hospital capacity. Then, the 2SFCA method was applied to reveal the supply/demand balance for each street with respect to accessibility of medical resources. Finally, the global and local Moran indices were used to obtain the spatial differentiation characteristics of this accessibility.

Kernel density analysis

Kernel density analysis is a method of non-parametric estimation of spatial point patterns based on density, with values varying with distance from the central point. This method takes into account that the service provided by medical facilities declines with distance, which reflects the length of travel for medical treatment (Yu & Ai, 2015). We used this tool in ArcMap 10.7 (ESRI, Redlands, CA, USA) to analyze the kernel density for all hospitals in the central city of Beijing. The calculation formula is as follows:

$$O_i = \frac{1}{n\pi r^2}\sum_{j=1}^{n} K_j\left(1-\frac{d_{ij}^2}{r^2}\right)^2 \quad \text{(Eq. 1)}$$

where O_i represents the kernel density of facility point i; K_j the weight value of facility point j; d_{ij} the distance between facility point i and research object j; r the bandwidth; and n the number of research objects j within the bandwidth range r (Ling, 2018).

Service area analysis

Considering the travel demand for medical treatment by residents, including the time to reach medical facilities, as cost, we summarized the service areas of hospitals in the central urban area of Beijing as done by Utami *et al.* (2022). We calculated the ratio of the population covered by each level of hospital in each service area to the total population to provide a reference for setting the search radius. Based on the functional positioning of hospitals in the Hospital Hierarchical Management Standards in China and the concept of a circle indicating 15-minute access to medical service by walk mentioned in the "Healthy China 2030" (State Council of the Central Committee of the Communist Party of China, 2016), we calculated the service range of primary hospitals, with the service radius set at time intervals. We also calculated the service range based on driving, with the service radii set at 5, 10 and 15 minutes for the secondary hospitals and 5, 15 and 30 minutes for the tertiary hospitals. The formula used was the following:

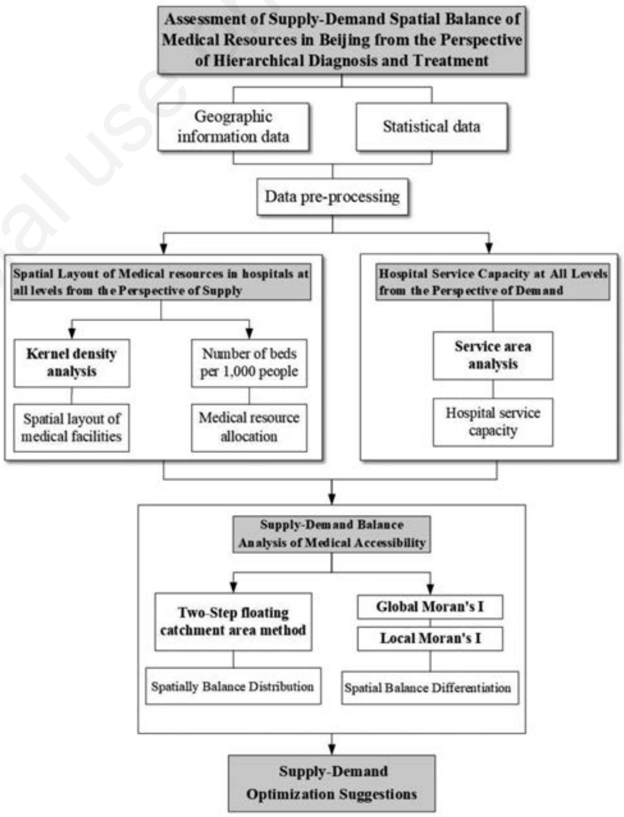

Figure 2. Technical flow chart.

Table 1. Road speed assignment criteria.

Road category	Speed (km/h)	Road connection	Speed (km/h)
Motorway	80	Motorway_link	60
Trunk	80	Trunk_link	60
Primary	60	Primary_link	40
Secondary	40	Secondary_link	30
Tertiary	30	Tertiary_link	30

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$$A_b = \Sigma_{x\epsilon(t\leq t_d)} S_x \quad \text{(Eq. 2)}$$

where A_b represents the service area under impedance b; t_d the travel time under interruption value d; and s_x the service range of any point x on the road. Impedance refers to the cost attribute of the service area and interruption to the specified service area range to be calculated. Since travel speeds is influenced by preset speed limits (Luo & Wang, 2003), Meng and Zhang (2017) divided roads into four categories: expressways, main roads, secondary roads and branch roads and assigned corresponding speed values. Zhao *et al.* (2018b) assumed that each movement occurred at the same speed and assigned the road speed according to the road network and road class. We obtained the length of the road elements in the road network by geometric calculation and the travel time by dividing the road length by the road speed that was divided into two modes: walking and driving. We used a walking speed of 1.25 m/s (given as reference speed in the Gaode Map API) and assigned the driving speed according to the OSM data description, with the specific criteria, as shown in Table 1. To be more consistent with the real situation of most residents' medical travel, and to take into account the results of the service range analysis of hospitals at all levels, the search radius by car for the secondary and tertiary hospitals in this section was set to 10 minutes and 15 minutes, respectively. Considering that the higher the hospital level, the wider the service range, the search radius of Grade-A tertiary hospital was set to 30 minutes by car. With reference to the "Healthy China 2030", the search radius of the primary hospitals was set at 15 minutes on foot. These criteria were used as the search radius to calculate the medical accessibility of each residential site, and the results were aggregated by street (converting the number of beds per capita into the number of beds per 1,000 people) to obtain the accessibility of each street, *i.e.* the number of beds per 1,000 people within the search radius.

Supply/demand distribution

We summarized the number of hospital beds per thousand people within the search radius for each hospital level in each street, which gave us a mathematical figure (A) for the degree of accessibility of the hospitals. According to the corresponding standards in the Beijing Urban Master Plan (2016-2035) and the Special Plan for Medical and Health Facilities in Beijing (2020-2035), the number of beds per 1,000 people in Beijing in 2016 was set as the qualified line in the supply/demand balance, the number of beds per 1,000 people in Beijing plan in 2020 and 2030 was set as a good line and an excellent line respectively.

Because of the large difference with regard to hospital beds, the accessibility at each level was expressed in numerical form in order to compare the allocation of medical resources at each level more clearly in the graded evaluation. In the comprehensive assessment, the supply/demand balance of medical resources was evaluated by grade to obtain the current status of the overall allocation of medical resources in the central city of Beijing (Table 2).

Accessibility analysis

After searching for all supply points within the search radius of each demand point for the 2SFCA method, the supply-demand ratio (R) is summarized to obtain the accessibility value (A) (Peng *et al.*, 2012). The setting of the search radius refers to the service scope of the three levels of hospitals under different travel needs. The service area analysis results were used to establish the search scope, with the hospital as supply point and the residential buildings as demand points. In order to ensure the accuracy of the experiment, we created a net with cells measuring 500*500 m taking the centres of the cells as residential points. The population in the each residential area was weighted based on the number of permanent residents of each street and the 100 m^2 Worldpop population raster dataset for 2020. The calculation formula used was the following:

$$Q_j = \frac{N_j}{N} \cdot Q \quad \text{(Eq. 3)}$$

where j represents the resident point; Q_j the weighted population of the resident point; N_j the population of the resident point (from the raster dataset); N the total population of the resident points in the street (from the raster dataset); and Q the average population of the resident points (the resident population of each streets). For each hospital location j, all resident locations k within the threshold travel time d_0 from the catchment area j were searched and the number of hospital beds-to-population ratio (R_j) within the catchment area calculated by the following equation:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\leq d_0\}} P_k} \quad \text{(Eq. 4)}$$

where P_k represents the population of region k whose centroid falls within the catchment (*i.e.* $d_{ky} \leq d_0$); S_j the number of hospital beds at location j; and d_{kj} the travel time between k and j.

For each resident location i, all hospital locations j within the threshold travel time d_0 from the catchment area i were searched and the number of hospital beds-to-population ratios R_j at these locations summed up by the following equation:

$$A_i^F = \sum_{j\in\{d_{ij}\leq d_0\}} R_j = \sum_{j\in\{d_{ij}\leq d_0\}} \frac{S_j}{\sum_{k\in\{d_{kj}\leq d_0\}} P_k} \quad \text{(Eq. 5)}$$

where A_i^F represents the accessibility at resident location i; R_j the number of hospital beds-to-population ratio at hospital location j, whose centroid falls within the catchment centered at i (*i.e.* $d_{ky} \leq$

Table 2. Evaluation criteria for the supply/demand balance of medical resources.

Accessibility level (A)	Supply/demand balance (grade)
10.15	Unqualified
10.16-11.56	Qualified
11.57-13.94	Good
≥13.95	Excellent

d_0); and d_{ij} the travel time between i and j. A larger value of A_i^F indicates a better accessibility for a location (Luo & Wang, 2003).

Global spatial autocorrelation

In order to assess the spatial distribution characteristics of accessibility of each hospital, we used Global Moran's *I* (1950) to analyze the differences and overall correlations measured at the street scale. The formula for Moran's I index is the following:

$$Moran's\ I = \frac{n\sum_{i=1}^{n}\sum_{j=1}^{m} w_{ij}\left(x_i-\bar{x}\right)\left(x_j-\bar{x}\right)}{\sum_{i=1}^{n}\sum_{j=1}^{m} w_{ij}\sum_{i=1}^{n}\left(x_i-\bar{x}\right)^2} \quad \text{(Eq. 6)}$$

where n is the total number of geographic spatial units; x_i and x_j the observed values of healthcare accessibility at the spatial units i and j; $\bar{x}$ the proportion of healthcare accessibility in the geographic space; and w_{ij} the spatial weight matrix. The Z-score represents the significance level of Global Moran's *I,* whose values vary between -1 (negative correlations) and 1 (positive correlations), with values near 0 indicating that accessibility is independently distributed and the values thus unrelated.

Local spatial autocorrelation

Local spatial autocorrelation (Anselin, 1995) divides clustering into four types: High-high (HH) and low-low (LL) types, which are positively correlated, while high-low (HL) and low-high (LH) are outliers, which are negatively correlated. We used Local Moran's *I*, which complements the global approach by analyzing the distribution of spatial differences of adjacent locations. The formulas are:

$$Local\ \ Moran's\ I = \frac{\left(x_i-\bar{x}\right)\sum_{j=1}^{m} w_{ij}\left(x_j-\bar{x}\right)}{S^2} \quad \text{(Eq. 8)}$$

where x_i and x_j are the observed values of accessibility for the spatial units i and j; $\bar{x}$ the proportion of medical accessibility in geographic space; w_{ij} the spatial weight matrix; n the number of spatial units; S^2 the variance of medical accessibility for the spatial unit i; and m the number of spatial units adjacent to i.

Results

Spatial hospital distribution

The nuclear density analysis for the tertiary hospitals showed a relatively concentrated distribution (Figure 3a), with the majority located in two core districts Dongcheng (centre) and Xicheng (northern part). Additionally, some tertiary hospitals were seen in the peripheral areas of the core region, such as in the districts Chaoyang (western part) and Haidian (southern part) as well as the western extension of Chang'an Street, with the secondary hospitals (Figure 3b) having a more dispersed distribution, with most presence within the Fourth Ring Road. The densest area for these hospitals was seen in the districts Xicheng (southern part) followed by Xicheng (central part) and Dongcheng (northern part). The distribution in Dongcheng and Xicheng was found to be relatively balanced, with the northern distribution more dispersed than the southern.

The primary hospitals are more numerous exhibiting a mainly circular distribution (Figure 3c). The strongest presence was seen around the core region east and west of Chang'an Street. However, there are fewer hospitals of this type in the centre, particularly in the districts Chaoyang, Haidian, Shijingshan and Fengtai. The distribution of primary hospitals in the study area was seen as relatively balanced.

Overall, the analysis of the central urban area of Beijing indicates that all the hospitals are mainly circularly distributed around the centre, with a gradual decrease towards the periphery, similar to the distribution of the primary hospitals (Figure 3d). There are also many hospitals in the southern part of Haidian District and the western part of Chaoyang District, while hospitals in other peripheral areas are relatively sparse

Number of hospital beds

Although the tertiary hospitals have the largest number of beds, there are large differences per 1,000 people per street (Figure 4a). Most streets in Xicheng and Dongcheng districts have more beds in the tertiary hospitals, while, in some areas, such as in the eastern part of Chaoyang District and the north-western part of Haidian District, the number of beds per 1,000 people is relatively low. The total number of beds in the secondary hospitals is lower, and so is the number of beds per 1,000 people (Figure 4b). However, the districts Xicheng and Dongcheng have a comparatively higher number of beds and their distribution was found to be relatively balanced. However, in many streets of Chaoyang and Shijingshan districts, the number of beds per 1,000 people is generally low. The number of beds in the primary hospitals is relatively small (Figure 4c) and the difference with respect to the number of beds per 1,000 people did not vary significantly between streets. However, some streets in Haidian and Fengtai districts have small populations and the number of beds per 1,000 people is relatively high there. Overall, the allocation of hospital bed resources among the streets in Beijing's central urban area of is not balanced (Figure 4d). While most districts and streets have relatively abundant and well-distributed bed resources, the number of beds per 1,000 people is relatively low in some areas.

Hospital service capacity

The tertiary hospitals are mainly located in the central urban areas, with some in newly developed areas (Figure 5a). The coverage basically covers most residents within and outside the Fifth Ring Road except for the mountainous areas and where road networks have yet to be constructed. Only 15.4% of residents in the study area can reach these hospitals within a 5-minute drive; while 82.4% can reach them within a 15-minute drive and almost all (93.5%) within a 30-minute drive. The coverage of secondary hospitals includes mainly the streets and administrative areas around the ring roads but different travel time costs are offered (Figure 5b). Only 13.9% of residents can reach these hospitals within a 5-minute drive; 50.6% within a 10-minute drive, while 84.3% of residents within the Fifth Ring Road, in the southern part of Fengtai District and the Capital Airport area can reach these hospitals within a 15-minute drive. With exception of the Capital Airport area, each street is equipped with at least one primary hospital (Figure 5c), so 20.4%, 55.3% and 77.6% of residents can reach primary hospitals within a 5-minute, 10-minute and 15-minute walk, respectively. By comparing the service coverage within a 15-minute walk in Figure 5c with the weighted population distribution of residential points in Figure 5d (calculated by Eq. 3), it can be found that the service coverage of these hospitals basically covers the areas with high population density. Indeed, the central urban area of Beijing forms a 15-minute health service circle achieving dynamic full coverage of health service for the residents in each street and township.

Overall, by summarizing and comparing the population coverage of all the hospitals under, we obtained a measure of available service capabilities but under different travel demands (Table 3). As travel times increase, the service range of hospitals expands and the population coverage for each type of hospital increases. At the maximum travel cost, the service range of all levels of hospitals can cover most residents in the city. Specifically, 82.4% of residents can reach a tertiary hospital within a 15-minute drive, which covers most residents in the urban area; 50.6% of residents can reach a secondary hospital within a 10-minute drive, which covers most residents at the district-level; and 77.6% of residents can reach a primary hospital within a 15-minute walk, thus forming a 15-minute circle offering full coverage at the township level.

Supply/demand balance

Using the OD cost matrix, which finds and measures the least-cost paths along the network from multiple origins to multiple des-

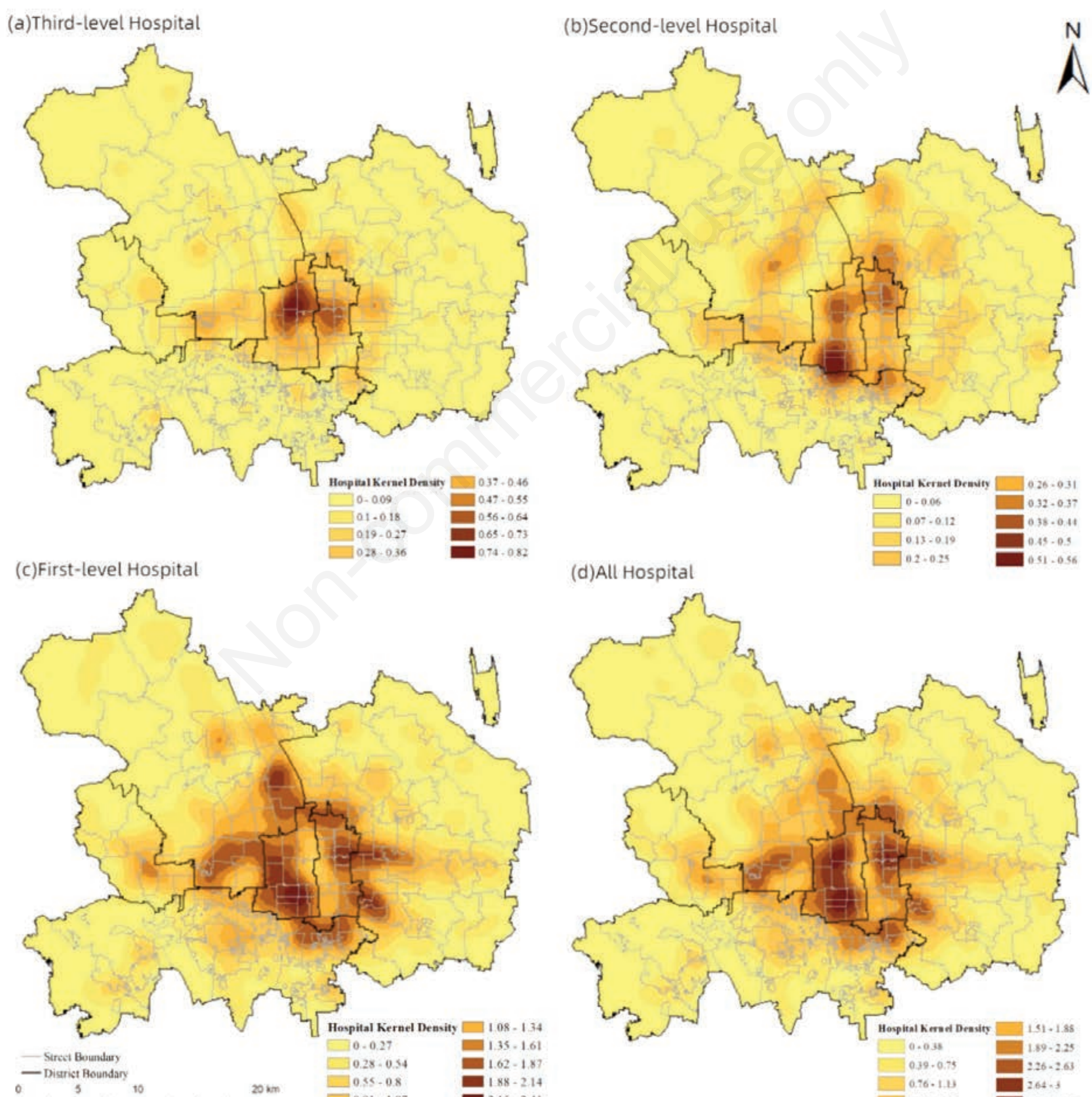

Figure 3. Results of the nuclear density analysis of hospital distribution.

Table 3. Service capacity of hospitals at all levels.

Hospital level	Travel cost	Population covered (%)
Tertiary	5-minute drive	15.4%
	15-minute drive	82.4%
	30-minute drive	93.5%
Secondary	5-minute drive	13.9%
	10-minute drive	50.6%
	15-minute drive	84.3%
Primary	5-minute walk	20.4%
	10-minute walk	55.3%
	15-minute walk	77.6%

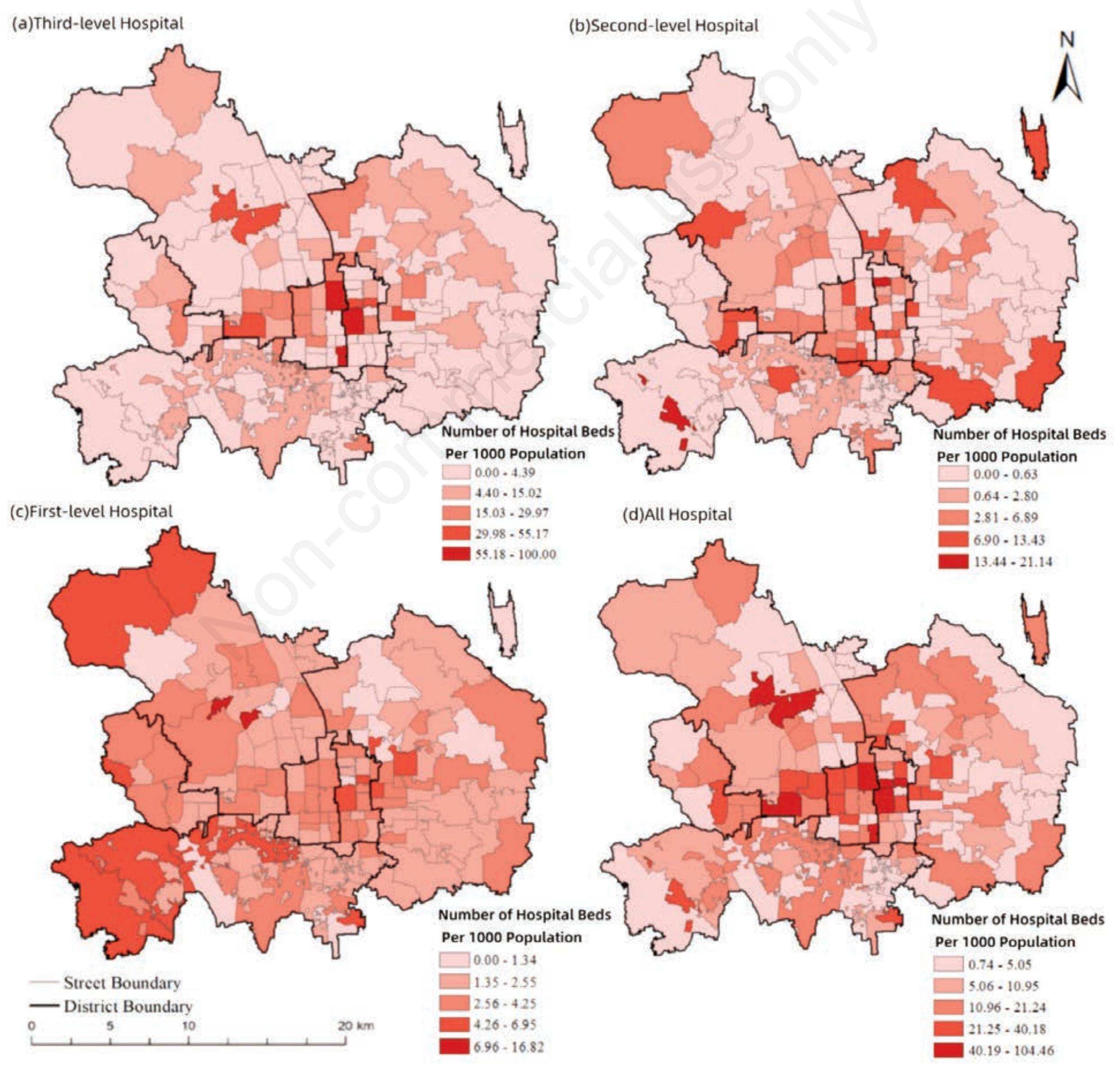

Figure 4. Number of beds per 1,000 people in each street.

tinations, we calculated the average travel time of driving to secondary and tertiary hospitals in the study area as 12.23 minutes and 14.58 minutes, respectively. The accessibility of tertiary hospitals, as shown in Figure 6a, was found to have an average value of 7.25, indicating the availability of abundant medical resources. On the other hand, their spatial distribution was not found to be uniform but rather a gradually decreasing accessibility from the centre to the periphery, with a single-centre, concentric distribution pattern. This is because most tertiary hospitals do not have ample bed resources and they are located in the central and western regions. The first concentric circle is a high-accessibility area comprising Xicheng and Dongcheng districts of the city centre and the southern part of Haidian District. This circle has numerous tertiary hospitals and the supply and demand of medical resources are well balanced. The second concentric circle is a moderately high-accessibility area covering the districts Chaoyang (the western part), Haidian (the central part), Fengtai (the north-eastern part) and Shijingshan (the eastern part). This circle has the highest number of streets and the largest area. Although it has few tertiary hospitals, its proximity to the core area of Beijing and the existing transportation network makes for good accessibility. Thus, the supply and demand of medical resources were deemed to be balanced. The third concentric circle is a low-accessibility area, covering the districts Chaoyang (the eastern part), Haidian (the north-western part) and Fengtai (the south-western part). This circle is on the periphery of the study area, far from the urban ring road network, and it has only one tertiary hospital. Therefore, the accessibility in this circle is the lowest, and the supply and demand of medical resources deemed imbalanced existing supply cannot meet the medical needs.

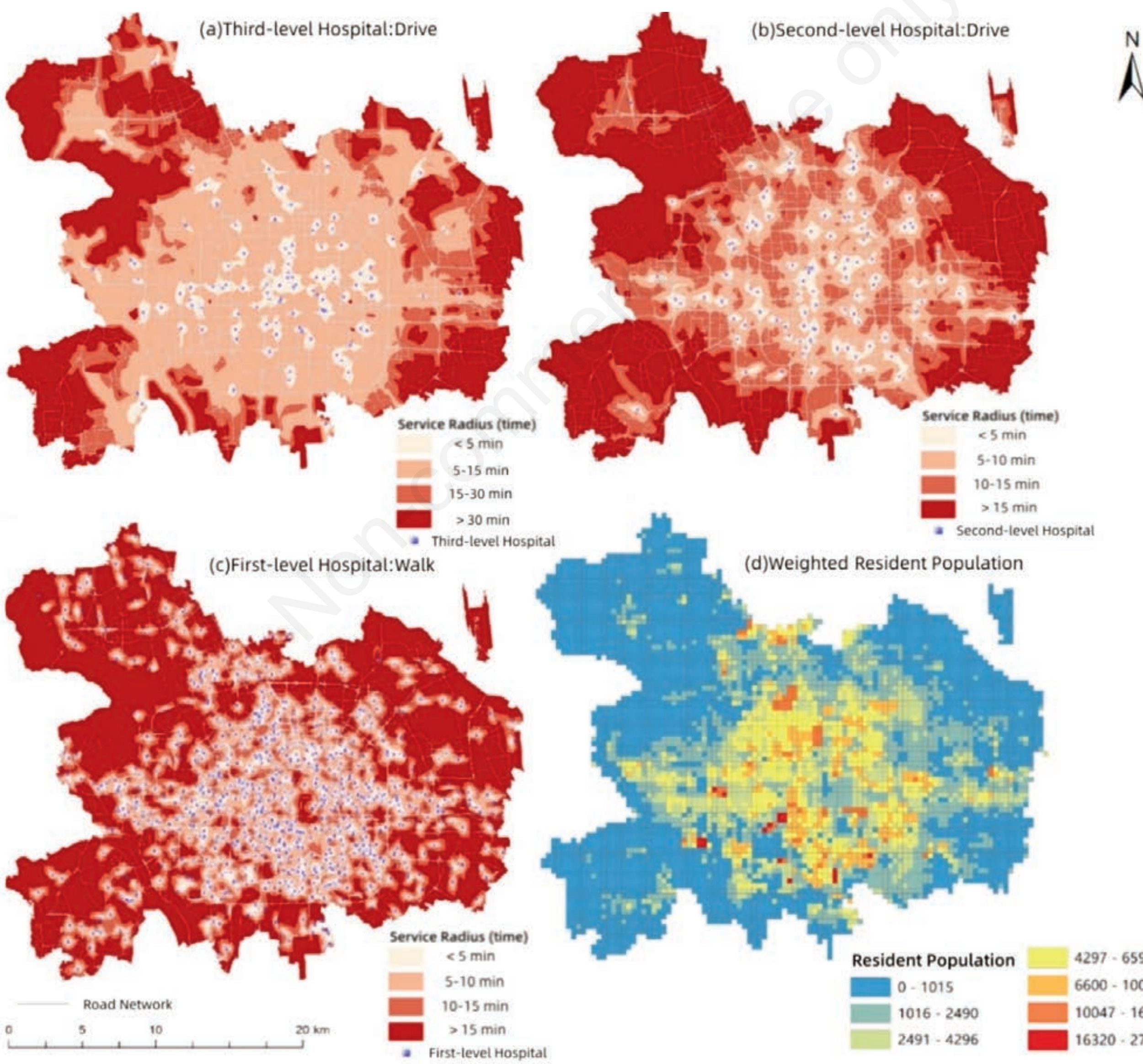

Figure 5. Scope of hospital services.

The accessibility of secondary hospitals, as shown in Figure 6b, delivered an average value of 2.26, indicating relatively scarce resources. The accessibility exhibits a dual-centre distribution pattern, with high-accessibility centres gradually decreasing towards the peripheries. Chongwenmenwai Street in the southern part of Dongcheng District and Changxindian Street in the western part of Fengtai District form two medical centres surrounded by a relatively large number of secondary hospitals with abundant medical resources. However, although the Changxindian Centre has only one secondary hospital nearby, the surrounding streets have only a small population, so the hospital can meet the medical needs of the local residents. Therefore, accessibility is good, and the supply and demand of medical resources balanced. The street of Capital Airport also has good medical accessibility because of the Third Hospital of Beijing University (Capital Airport Hospital Area) next to the airport. In addition to the above areas, there are fewer hospitals in the Shijingshan District, central Haidian District and south-eastern Chaoyang District, forming a "geographic depression" of medical accessibility, that is, the imbalance between the supply and demand here results in a situation where the supply of resources cannot meet the medical demand of the surrounding residents.

The resource allocation in the primary hospitals is extremely uneven resulting in a distribution pattern at an average value of 3.99 called "higher in the East and West, lower in the Centre", which means that the accessibility to primary hospitals is significantly lower in the central area than in the peripheral areas (Figure 6c). Although the central area has numerous primary hospitals and

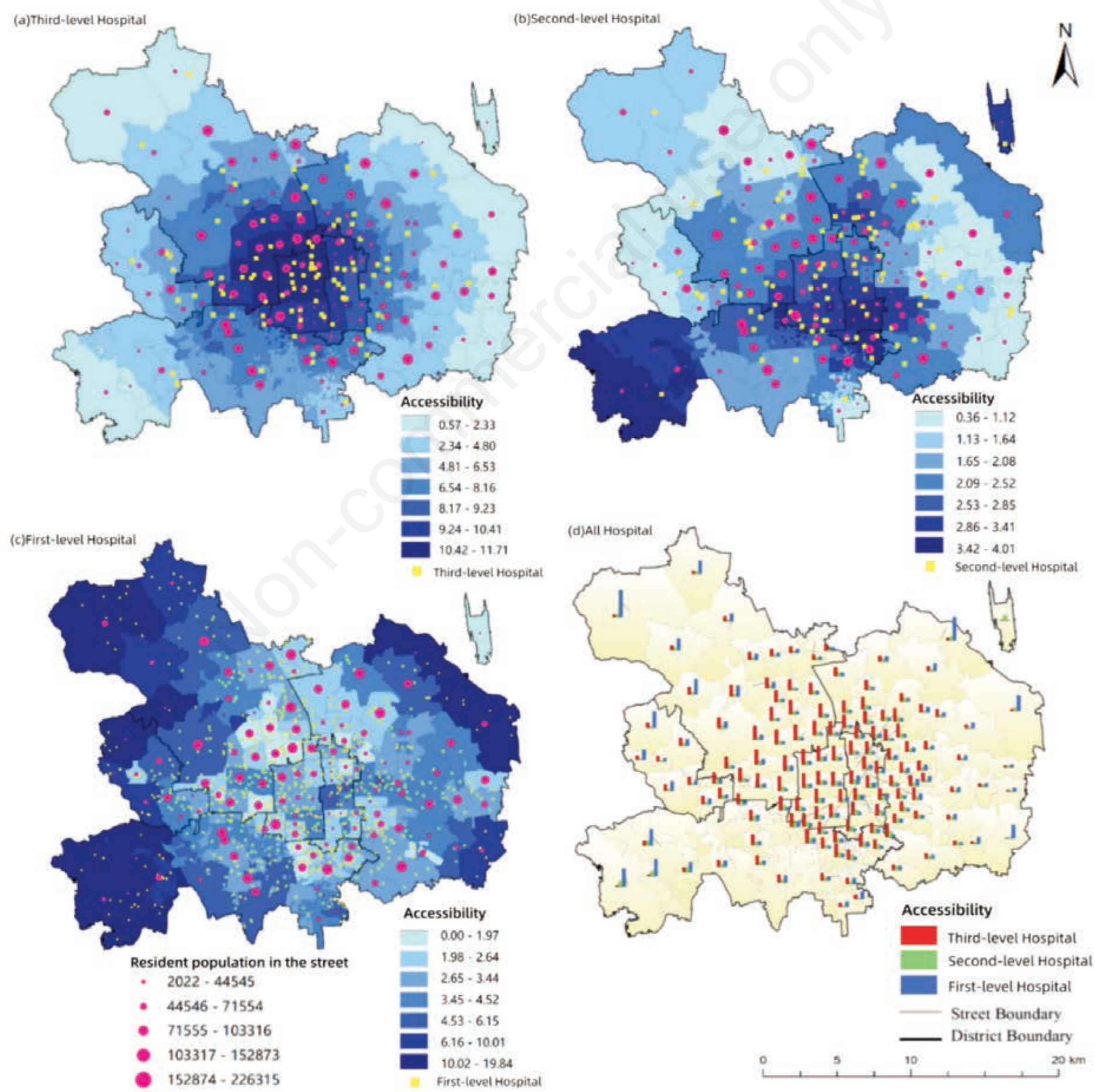

Figure 6. Accessibility of medical resources.

convenient transportation, most of the streets in this area have large populations and that limits the availability of medical resources contributing to a supply/demand imbalance. For example, there are nine primary hospitals in Haidian District's Beitai Pingzhuang Street, but with a population of 164,000, the basic medical resources do not meet the needs of so many people. In contrast, the suburban area of Sunhe Town has only two primary hospitals, but its population is only one-sixth of that of Beitai Pingzhuang Street, resulting in a higher accessibility value. Similarly, Wanliu District and Donghuamen Street in the central area also form sporadic high-value areas due to their small population sizes. Abnormally, Capital Airport Street has zero accessibility because of absence of primary hospitals, but that is due its special function for the airport.

From the perspective of using the street as unit in this research, the accessibility to tertiary hospitals in the core districts is significantly higher than that of primary and secondary hospitals (Figure 6d). The value was seen to gradually decrease towards the periphery, with a more significant decreasing trend in the East than in the West, indicating that the supply/ demand ratio of medical resources for tertiary hospitals in the surrounding areas of the core area is more balanced. The presence of secondary hospitals was found to be in a generally low level in the streets within the study area, indicating that the supply/demand ratio there is more uneven. In some peripheral street districts outside the study area, such as Sujia Tuo Street, Sunhe Town and Wangzuo Town, the accessibility to primary hospitals was seen as significantly higher than that of the secondary and tertiary hospitals. The smaller populations of these street districts give them a higher accessibility resulting in a more balanced supply/demand ratio. For areas located in the districts Chaoyang (central-southern part), Haidian (the eastern part), Fengtai (the eastern part) and some other areas between the centre and the periphery of the study area, the accessibility values for medical resources in hospitals at all levels appeared low.

The evaluation of the balance of medical resources in the central urban area is shown in Figure 7, which indicates that the allocation of medical resources in the central urban area must be deemed as not balanced. Overall, the balance of medical resources

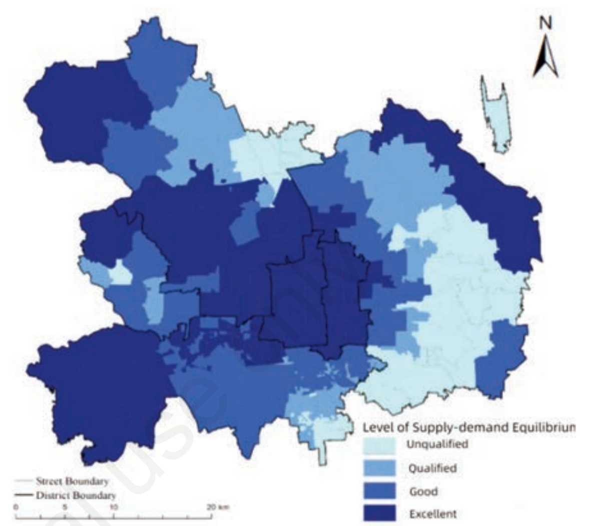

Figure 7. Rating of the supply-demand balance of medical resource in the central city.

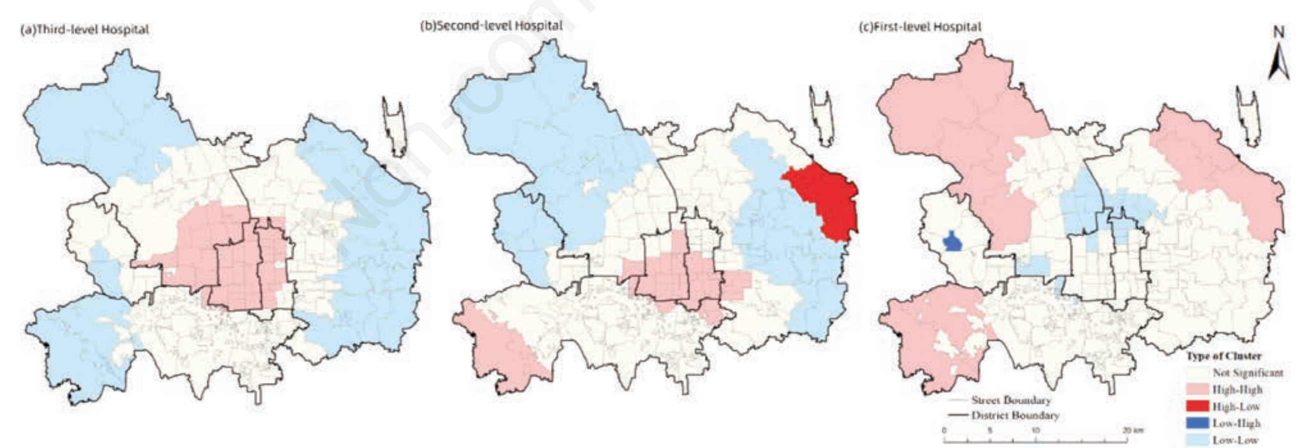

Figure 8. Clustering diagram of accessibility of medical resources.

Table 4. Global statistics of accessibility to healthcare.

Hospital level	Moran's *I*	Z-score	P-value
Tertiary	0.814	15.831	0.000
Secondary	0.757	14.721	0.000
Primary	0.502	10.195	0.000

in the central and western regions is significantly better than that in the eastern region. If the population of each street were aggregated according to the evaluation level, 42.9% of the residents enjoy an excellent level of balance of medical resources indicating that these areas have a surplus of medical resources, particularly in the core and the surrounding areas, as well as in the north-eastern and western peripheral areas. Combined with Figure 6d, it was found that the above-mentioned areas are outstanding with respect to accessibility of primary or tertiary hospitals. 30.1% of the residents enjoy a good level of balance of medical resources, mainly distributed in the radiation area outside the core area; 11.9% have access to medical resources with a qualified level of supply and demand, mainly for residents in some streets in Chaoyang (the northern part), Haidian District (the central part) and some streets in Shijingshan and Fengtai. However, 15.9% of the residents live in areas that must be termed unqualified with respect to medical resources. This mainly concerns the residents in the currently rapidly developing areas in eastern Haidian District and central/southern Chaoyang District, which illustrates that rapid development lead to popular increase that often outpaces support leading to an imbalance of supply and demand for medical resources.

Spatial balance differentiation

Global Moran's I for hospital accessibility gave a Z-score of >2.58 at $p<0.01$, which indicates a significant spatial correlation of medical accessibility by street unit. The results are shown in Table 4, where the average Moran's I for accessibility of medical resources in hospitals at all levels were close to 0.7, indicating that the distribution characteristics of medical accessibility have a positive spatial correlation and strong autocorrelation, indicating a significant clustering effect within the study area. With the p-value less than 0.01, and the Z-score much higher than 2.58, the distribution of spatial clusters indicating accessibility in streets has an extremely high confidence level.

Spatial heterogeneity pattern

The cluster map of the accessibility of tertiary hospitals is shown in Figure 8a. The HH cluster areas of the accessibility of tertiary hospitals were found to be mainly concentrated in the southern part of the districts of Xicheng, Dongcheng and Haidian (the southern part). The tertiary hospitals are also concentrated in this area, showing obvious spatial positive correlation, with high-value areas of medical accessibility with clear clustering features. There were no outliers. The LL cluster areas are mainly concentrated in the northern part of the districts of Haidian, Chaoyang (eastern part) and Fengtai (western part). This cluster type has also an obvious spatial positive correlation, indicating low-value areas of medical accessibility, with low values surrounding the area and clear clustering features, requiring strengthening the construction of tertiary hospitals in this area.

The cluster map of the accessibility of secondary hospitals is shown in Figure 8b. The HH cluster areas are mainly concentrated in the southern part of the core area in the districts of Dongcheng, Xicheng and Fengtai (the western part). The Jinzhan Town area is a HH cluster area, which has no obvious clustering features, and its high values are mainly influenced by the Peking University Third Hospital (Capital Airport branch). There were no outliers. The LL cluster areas are mainly concentrated in the eastern part of the districts Chaoyang, Haidian (the north-western part) and Shijingshan (the western part).

The cluster map of the accessibility of primary hospitals is shown in Figure 8c. The HH cluster areas are mainly concentrated in the districts Haidian (the north-western part), Chaoyang (the north-eastern part) and Fengtai (the western part). There were no HL clusters but on LH cluster (the Jinding Street area in Shijingshan District), which had no obvious clustering features. This street has a population of 68,000 but only one primary hospital, which cannot meet the medical needs of residents, hence forming a LH cluster area. The LL cluster areas were found at the intersection of the four districts: Xicheng, Dongcheng, Haidian and Chaoyang in the upper-middle part of the study area.

Key findings

The hospitals in Beijing's urban area of are mainly concentrated in the centre. Although this matches the population distribution, there is still an imbalance and irrationality in the supply and demand of medical resources with signs of oversupply in the city core and immediate, surrounding areas,

The tertiary hospitals are rich in medical resources, and although the great majority of the residents can reach these hospitals within a 15-minute drive, their spatial distribution is uneven, with a circular distribution pattern with the numbers gradually decreasing from the core area to the periphery.

There is an overall, quite severe shortage of secondary hospitals, which are mainly distributed within the Fourth Ring Road. Only 50.6% of the residents can reach them within a 10-minute drive. There is a dual-center distribution pattern, with high-value centres gradually decreasing towards the periphery, and low accessibility clustering in some districts.

The distribution of primary hospitals is the most uneven, as they are mainly distributed around the core area and along an east-west axis. Although the majority of the residents can reach them within a 15-minute walk, the accessibility showed an "east-west high, middle low" distribution pattern, indicating that the medical resources of primary hospitals cannot meet the needs of the large population in the central area. The low accessibility clustering is located in the middle-upper part of the research area.

Discussion

The contribution of this study is to construct an assessment framework of supply-demand spatial balance of medical resources from the perspective of hierarchical diagnosis and treatment, and to present a typical assessment example of Beijing. Specifically, this study utilized GIS spatial analysis techniques to investigate the spatial distribution, service coverage, and supply-demand situation of medical facilities in the central urban area of Beijing from the perspective of balance medical resource supply and medical treatment needs. Taking the street as the smallest research unit, various methods, such as kernel density analysis, service area analysis, 2SFCA method, and spatial autocorrelation analysis, were used to reveal the supply-demand balance of medical resources in hospitals at all levels and whole in the central city of Beijing under the hierarchical medical system.

Although the spatial distribution of hospitals in Beijing is generally consistent with the administrative regions, it is inconsistent with population demand as available resources are more inclined to serve the urban central area (Gong *et al.*, 2021; Meng & Zhang, 2017; Zhao *et al.*, 2018a). In line with these results, this study showed that hospitals in Beijing are mainly concentrated in the core and surrounding areas, while the number of hospitals in the peripheral areas is relatively small and the supply of medical resources there cannot meet the needs. Through service area analysis, we found that hospital catchments match the population aggregation areas but as the proportion of the population covered increases, this comes at the cost of increasing travel times. Indeed, the service range of hospitals of all levels covers most of the urban residents, but only at the penalty of including the maximum travel cost of a 30-min drive used in this study.

From the supply and demand perspective, we found in the central urban area of Beijing lacks balance between supply of medical resources and population demand and that this imbalance comas in two types: excessive accessibility (as is the case in the core area and its surrounding areas) and relatively low accessibility (as in the northern part of Chaoyang District and the central part of Haidian District). In addition, the supply scale and accessibility distribution pattern of medical resources vary among hospitals of different levels. Among them, the supply of resources in the secondary hospitals is generally scarce, while they are often abundant in the tertiary hospitals. In contrast, the supply in the primary hospitals cannot meet the demand for basic medical resources in the central area with large populations. As evident from Figure 3, the density value of the tertiary hospitals is greater there than that of the secondary ones. As indicated in Figure 4, the tertiary hospitals possess a higher bed count than the secondary ones. Moreover, the tertiary hospitals are assigned larger service radii, thereby encompassing a broader service area. As a result, the coverage for the population and accessibility of these hospitals are higher compared to secondary ones. Overall, the supply and demand of medical resources in the central urban area of Beijing are currently not balanced. The resource allocation still faces the problems of surplus in the core area and inadequate supply in the peripheral areas. Although the spatial distribution of hospitals of all levels in the central urban area of Beijing is compatible with the population distribution, the supply and demand situation with regard to medical resources at different levels is different.

In terms of optimizing the allocation of medical resources, we recommend: i) to address the imbalance between the supply and demand of medical resources in tertiary hospitals, the government could enrich high-quality medical resources in peripheral areas by building branch hospitals of existing tertiary hospitals, especially in LL cluster areas, as well as rapidly developing areas such as Zhongguancun Software Park, Lize Business District, and the urban sub-centre; ii) service area analysis showed that only 50.6% of residents in the central urban area of Beijing can reach a secondary hospital within a 10-minute drive, and the number of beds and physicians in many secondary hospitals currently does not meet the evaluation criteria for secondary hospitals as given by the Hospital Hierarchical Management Standards. To address the overall low accessibility and scarcity of medical resources in secondary hospitals, the government should not only build new branch campuses of secondary hospitals in sparsely distributed areas, such as the central part of Haidian District and the southeast of Chaoyang District, where there are relatively few hospitals, but also improve the resource and service levels of existing secondary hospitals, strengthen the supervision and review of secondary hospitals; iii) although there are many primary hospitals and a 15-minute medical service circle has been initially formed, the supply of primary hospitals currently cannot meet the large population base in the urban area. There are some areas where medical resources are tight, and people have difficulties in seeking medical treatment, especially in LL cluster areas where the population of streets ranks among the top in the study area. Therefore, it is necessary to strengthen the construction of primary healthcare facilities and add clinics for infectious diseases in these areas, further expand the supply of medical resources and increase the manpower, give full play to the role of community health service centres and other primary hospitals as "sentinels" and improve their ability to respond to emergency epidemic situations.

In terms of improving the macro planning of basic public services, we recommend: i) to improve the health care system, it is necessary to consider the rational distribution of hospitals within the jurisdiction to form distribution pattern at different levels, so that various levels of medical resources can be fully utilized and avoid over-concentration of hospitals of the same level; ii) in conjunction with the current policy of non-capital function relocation in Beijing, some medical resources in the core area and its surrounding areas should be relocated to avoid the phenomenon of resource surplus in the core area; iii) for peripheral areas, the economic conditions within the region should be considered, and corresponding medical policies formulated, to attract high-quality medical resources. For areas with poor accessibility to medical services, the government could implement subsidy policies, such as providing residents with appropriate medical assistance, equipping medical resources reasonably and improving the service capacity of medical facilities; and iv) transportation is an important factor affecting the accessibility of medical resources, so it is also necessary to improve the road network structure, increase road density, and improve various modes of transportation to enhance travel convenience.

Limitations and future study

Among the limitations we note the following: i) the actual traffic situation was not considered, and the operation of assigning speed values to vector roads in this study did not consider the different congestion situations of different levels of roads; ii) due to the limitations of the research data, the population data used in this study were all permanent residents. The medical needs of short-term mobile populations and different age groups were not given sufficient consideration. However, "ensuring a healthy lifestyle and promoting the well-being of all people of all ages" is one of the global sustainable development goals, and it is necessary to analyze the supply-demand balance of medical resources by combining the population numbers of different age groups; iii) there are now many improved accessibility calculation methods, such as the enhanced 2SFCA (E2SFCA), which addresses uniform access issues by assigning weights to varying travel time zones, thereby accommodating distance decay. We are committed to enhancing the comprehensiveness of our analysis by incorporating the E2SFCA method into future investigations; and iv) due to the limitation of data access, in view of the shortage of medical beds in cities caused by COVID-19 and other public health emergencies, this paper only focused on the supply and demand of hospital beds. Scholars have already evaluated the fairness of the distribution of medical resources more comprehensively from the five dimensions of resident health status, medical service quality, health service utilization, social medical insurance coverage and medical health expenditure. These issues will be the direction of improvements in future research.

Conclusions

An imbalance between the supply of medical resources and the population demand in some areas of Beijing was revealed emphasizing the need for the government to optimize spatial planning and policy-making and promote improvements ensuring the rational and effective allocation and utilization of medical resources leading to reasonable and balanced medical security for epidemic prevention and control. This paper provides a decision-making reference for the balanced and reasonable allocation of medical and health resources leading to better utilization efficiency and equalization of public health services in line with SDG 3.8.

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