Research Paper

The accessibility assessment of medical facilities based on the hierarchical medical system
: A case study of Shenzhen, China

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Abstract

Due to the hierarchical medical system currently being promoted in China, the reasonable allocation of medical resources and equal medical services have become important research topics for urban planning. However, few studies have been conducted on the allocation of medical resources accounting for space accessibility based on the hierarchy of medical facilities and more refined population spatial units. This research assigned population into general and urban villages residential buildings (from building census data) to further refine the population data. By examining Shenzhen through a two-step 2SFCA, the present research evaluates the accessibility of community and regional medical facilities and spatial configuration at various referral rates by implementing GIS network analysis. The main findings of the present scrutiny are: 1) The overall development of medical facilities in Shenzhen is presently at the back of the first-tier cities in China, and there is a discrepancy in the accessibility of medical facilities between administrative districts; 2) Under the current conditions in Shenzhen, the best spatial configuration can be achieved only when the referral rate would be 70%-80%, indicating that primary medical resources are now weak in Shenzhen. In the future construction of medical facilities, there is a high requirement to classify and rank communities to formulate policies. This is essential for increasing the capacity of medical services in communities with poor medical resources. Additionally, the capacity of community health service centers should be enhanced and the treatment of minor diseases in senior hospitals should be evacuated to appropriately control the referral rate. This leads to attaining a balanced distribution and efficient exploitation of medical resources.

Keywords

Two-step 2SFCA, spatial accessibility, medical facilities, Shenzhen

1. Introduction

The outbreak of COVID-19 in 2020 caused a massive influence on people's lives and health as well as urban economic and social development (Xu, Zhu, and Liu, 2020). When dealing with such major health events, the capacity of medical facilities is significant. While the economy of China's cities, especially first-tier cities, has been quickly developed in recent years, the construction of supporting public service facilities such as medical care has relatively lagged; for example, bringing some problems such as the insufficient supply of facilities or poor accessibility due to irregular distribution (Si and Yin, 2020). From the demand side, as China's urban and rural construction enters a phase of high-quality development, the demand for public service facilities has been accordingly grown (Cai, Li, and Tang, 2012), and the contradiction happens because supply and demand are in a mismatch. Thereby, China should actively

promote a hierarchical medical system while optimizing the existing hierarchical construction of medical facilities. At the same time, the reform of the medical system can further promote the allocation of medical facilities so that their layouts and capacities at each level can be effectively matched. This will guarantee the overall optimal efficacy of medical facilities and alleviate the inconsistency between medical supply and demand as well. Research on the adaptability law of the medical facility layout under reform of the medical system can provide a vital reference for the rational layout of medical facilities and the efficient distribution of resources.

2. Literature review and concept analysis

2.1. Accessibility

Scholars have presented various definitions for accessibility. According to the focus of their research, *accessibility* could be defined as the cost of reaching the destination, such as distance cost or time cost (Ingram, 1971); or the convenience of obtaining various activities in a certain location (Wachs and Kumagai, 1973); or the potential for interaction between the starting point and the destination (Shen, 1998). Accessibility essentially describes the difficulty to get from one place to another, and what is typically exploited to research public service facilities is spatial accessibility. This means exploitation of space as an intermediary object to display the residents' convenience by utilizing a specific traffic system to travel from one area to another to participate in activities.

There exist many research approaches on accessibility, and the gravity model is a commonly implemented one. This model is usually exploited to assess the accessibility of an area based on the distance between starting point and destination, taking into account the supply of destination and the attenuation function. This model is often utilized in medical services (Henry et al., 2013; Neutens, 2015), parks and green spaces (Rosa et al., 2018), shopping (Helling and Sawicki, 2003), and other service places. Chinese scholars have evaluated the accessibility of medical facilities via an improved gravity model by integrating three factors, including service capacity of medical facilities, the population of residential areas, and resistance between medical facilities and residential areas (Song et al., 2010).

In addition, the two-step floating catchment area method, also called 2SFCA (Radke and Mu, 2000), has often been employed in researching the accessibility of public service facilities. The first step of this methodology is to take the supply point as the center, search for demand points within the service range, and calculate the supply-demand ratio of each supply point. The second step takes the demand point as the center, searches for the supply points within the threshold range, and sums up the supply-demand ratios of the searched supply points. The obtained calculated results are the accessibility from the demand point to the supply point. However, directly adopting this method to assess the accessibility of medical facilities would have some shortcomings. First, the hierarchical structure of medical facilities is not taken into account. Secondly, the method directly searches based on the service radius without considering the influence of the existing road network on travel.

2.2. Hierarchical structure of medical facilities

In researches of the location of public facilities such as medical, waste disposal, and education, the hierarchical structure analysis is commonly involved. It is mainly attributed to this fact that higher-level facilities can cover the services provided by lower-level ones, and service capacity as well as interrelationships of various facilities' levels should be considered (Farahani et al., 2014). For example, a 3-level hierarchical model was exploited to solve the location of maternal and perinatal health care facilities (Galvão, Espejo, and Boffey, 2002). A discrete hierarchical siting model was proposed for public

facility planning, in which multiple levels of demand and multiple types of facilities were taken into account (Teixeira and Antunes, 2008).

Generally, the hierarchical structure of facilities has four essential elements: flow pattern, service varieties, spatial configuration, and objective. Except for the objective, the other three elements reflect the pertinent spatial characteristics (Şahin and Süral, 2005). The flow pattern describes the flow features of services or goods on arcs between network nodes in the hierarchical facilities. One of which is the single-flow, starting from the lowest level and delivering to the highest level in sequence; another is the multi-flow, in which the services or goods can start from any level and reach the highest level sequentially or intermittently. The service varieties are divided into nested and non-nested. For nested-based service, the higher-level facilities cover the services provided by the lower-level ones, while in non-nested-based services, the facilities at each level will only give services associated with themselves. Additionally, the spatial configuration is a crucial factor to specify whether the given services or goods can be successfully matched with the hierarchical structure of facilities.

The hierarchical structure of medical facilities generally consists of demand points, low- and high-level medical facilities. Low-level facilities present diagnostic and treatment services for common illnesses, while high-level medical facilities accommodate patients with advanced diagnostic and surgical services. Most countries have various medical facilities, and this hierarchical system encourages patients to use a primary diagnosis at low-level medical facilities and then proceed to high-level medical facilities if required (Bashar et al., 2019). Commonly, this procedure makes medical services more efficient and allowing each level of medical facility to play its best role. This model has been successfully implemented in countries with strict primary care systems such as the United States (Donaldson et al., 1996), where the hierarchical structure of medical facilities is a single-stream, non-nested model (Fig. 1). In some low- and middle-income countries, due to the inadequate development of the medical system and the poor treatment of the low-level medical facilities, their primary care cannot be applied, so high-level facilities are needed to accommodate common diseases. The World Health Organisation (WHO) noted that patients in most countries usually bypass low-level medical facilities. In this case, the hierarchical structure of medical facilities is a multiple flow nested model (Fig. 2).
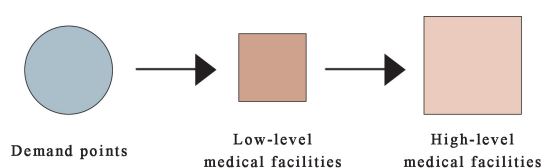

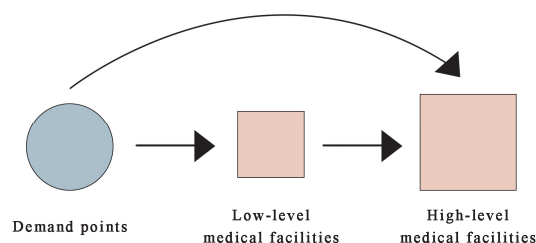**Figure 1. Schematic representation of a single-flow non-nested model.**

Figure 2. Schematic representation of a multi-flow nested model.

In the current medical system in China, patients can directly go to general hospitals without primary care (Zhang and Hu, 2020). In 2019, 95.8% of patients went directly to hospitals, and only 4.2% went to hospitals by referral (Wang et al., 2020). Commonly, people can freely choose various levels of medical facilities according to their conditions, such as community health service centers in less severe cases and general hospitals in more severe cases. Furthermore, some functions of community health service centers and general hospitals overlap. By this view, the hierarchical structure of medical facilities in China obeys a multi-flow nested model.

According to *the Guidance of the General Office of the State Council on Promoting the Construction of Hierarchical Medical System* in 2015, the hierarchical medical system should be enhanced with a focus on strengthening the grass-roots level and ranked the treatment of diseases based on the priority and difficulty (Chen, Zhang, and Liu, 2021). Medical facilities at diverse levels are in charge of different diseases, giving full play to the capacity of medical facilities at each level to avoid the situation that patients pile up in high-level medical facilities while low-level ones are empty. If the aforementioned system is strictly implemented in the near future, the hierarchical structure of medical facilities in China will evolve into a more efficient single-flow non-nested model.

3. Methodology

3.1. Research object

After the National Health Conference held in 2016, Shenzhen has entered into a new generation of the Guangdong-Hong Kong-Macao bay area and the demonstration pilot zone for socialism with Chinese characteristics. The medical system in Shenzhen had the mission of forming a "Shenzhen model" of a healthy China; however, the *Shenzhen Medical Facilities Setting Plan (2016-2020)* pointed out the following concerns regarding Shenzhen's medical facilities: 1. Insufficient medical resources. The number of hospital beds per 1,000 residents was lower than the national and Guangdong provincial averages in 2015; 2. Irregular allocation and utilization of medical resources. Medical facilities are unevenly distributed inside and outside the former Shenzhen special economic zone (SEZ), and the hierarchical medical system is commonly imperfect. Both these issues have made overcrowding in general hospitals and waste of resources of community health service centers; 3. The functions of medical facilities are not precise enough. There exist confused competitions between various categories of medical facilities, and the fragmentation of the service system is noticeable, with inadequatly effective connectivity between them.

Shenzhen is taken into account as the research object to evaluate the spatial accessibility of its medical facilities at various levels. By employing quantitative methods to reveal the spatial allocation of medical resources in Shenzhen and their spatial configuration to the hierarchical medical system, a solid basis for the construction of Shenzhen's medical system is provided in the near future.

As primary medical facilities in Shenzhen are configured on a community basis, community accessibility has been taken as the primary research unit. Shenzhen has undergone the expansion of SEZ, so there are significant differences in the development inside the former SEZ (Nanshan District, Futian District, Luohu District, Yantian District) and outside the former SEZ (Guangming District, Baoan District, Longhua District, Longgang District, Pingshan District, Dapeng District). A comparative examination of communities inside and outside the former SEZ has been carried out in the research (see Fig. 3).
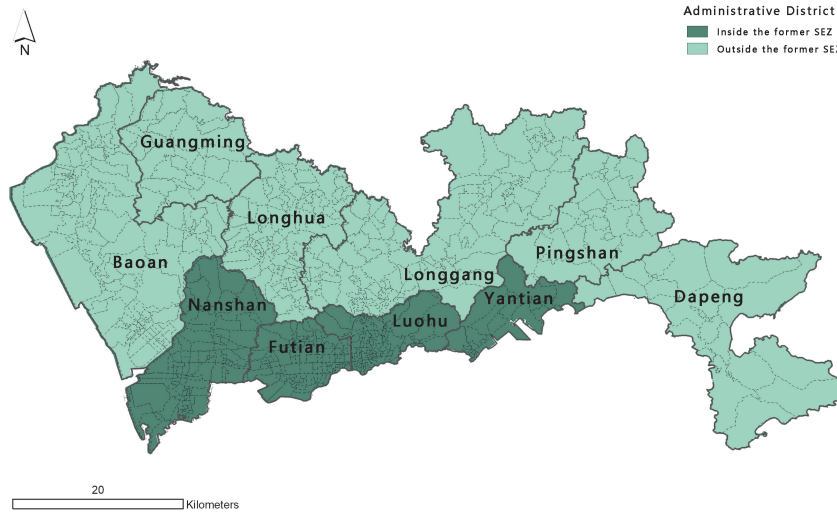
Figure 3. Administrative map of Shenzhen (Data source: Shenzhen administrative districts information. http://mzj.sz.gov.cn/).

3.2. Research methods

Both coordinates and number of employees of medical facilities in Shenzhen are first obtained. Then the population data of the community and building census data are brough togethor to assign the population to the residential buildings in urban villages and general residential districts. After obtaining the mentioned above data, the accessibility of each residential building is evaluated by implementing the two-step 2SFCA according to the road network data of Shenzhen using GIS network analysis. Then the accessibility of each community, administrative district, and the whole city are appropriately analyzed. After assessing the accessibility of the whole city, the spatial configuration analysis is performed to get the matching situation of high- and low-level medical facilities as well as the optimal referral rate in Shenzhen.

The two-step 2SFCA (Zhong, Yang, and Chen, 2016) is employed on the basis of assumptions of a hierarchical medical system. The discrepancies in the service radius of medical facilities at various levels are followed, and the accessibility assessment is conducted based on the road network data. In the first step, the accessibility from the demand point to the low-level medical facilities is assessed by taking the (i)th residential building as the demand point and its population as the number of patients. According to the hierarchical medical system, patients need to go through the referral procedure and go to the high-level medical facilities after reaching the low-level ones. This scheme represents the accessibility that is assessed in the second step.

Step I. Demand point: residential building i, number of patients D_k; supply point: low-level medical facility j in the threshold range d_0 from the demand point i; the total supply of the supply point S_j. In this step, there are D_k patients that go to the low-level medical facility, as given by Eq. (1):

$$A_i^F = \sum_{j \in (di_j \leq d_0)} \left[\frac{S_J}{\sum_{k \in (d_{kj} \leq d_0)} D_k} \right] \qquad (1)$$

where indicates the accessibility from the residential building to the low-level ones.

Step II. Demand point: the low-level medical facility j; supply point: the high-level medical facility p in the threshold range d_1 from the demand point j; the total supply of the supply point S_p. In the present step, patients from the low-level medical facilities go to the high-level medical facilities and receive treatment on the basis of the hierarchical medical system, as displayed by Eq. (2):

$$A_i^P = \sum_{p \in (d_{jp} \leq d_1)} \left[\frac{S_p}{\sum_{j \in (d_{jp} \leq d_1)} \left(\sum_{k \in (d_{ij} \leq d_0)} D_k \right)} \right] \tag{2}$$

in which represents the accessibility from the low-level medical facility to the high-level ones.

Finally, the overall accessibility of the (i)th demand point is calculated by:

$$A_i^M = A_i^F + A_i^P \tag{3}$$

If there would exist n demand points in the understudy region, then the overall accessibility of the region is given by:

$$A = \frac{\sum\limits_{1 \leq i \leq n} A_i^M D_i}{\sum\limits_{1 \leq i \leq n} D_i} \tag{4}$$

A hierarchical medical system determines whether patients require to go to a high-level medical facility based on the patient's condition and does so through referral, which involves a referral rate. The referral rate is determined by the capacity and quality of the low-level medical facilities. If the low-level medical facilities have more staff and capacity, fewer patients need to go to the high-level medical facilities, and thereby, the referral rate decreases. Suppose the referral rate be β, indicating that β of the patients from low-level medical facilities need to go to the high-level medical facilities. In order to realize the appropriate referral rate based on the current construction of medical facilities in Shenzhen, so that medical resources can be allocated more reasonably, a method of spatial configuration assessment is introduced to measure the matching between the number of patients referred and the construction of medical facilities at different levels:

$$P = \frac{\sum A_i^P \times D_i}{\sum A_i^M \times D_i} \tag{5}$$

where A_i^P represents the accessibility of high-level medical facilities of the demand point i, A_i^M denotes the overall accessibility of medical facilities of the demand point i, D_i is the population of the demand point i, and P is the ratio of the accessibility of high-level medical facilities to overall accessibility of medical facilities in a spatial unit. Based on the number of referred patients with a referral rate of β, the spatial configuration factor (F) is calculated by:

$$F = \frac{P}{\beta} \tag{6}$$

The closer F to 1, the more proportion of patients would be assigned through referral matches with the current construction of medical facilities, and for the case of $F=1$, the optimal referral rate is achived.

3.3. Research data

According to the Shenzhen government's online public information platform, the *Information about Medical Facilities in Shenzhen 2018* is carefully screened. This information would be beneficial in reaching data of a total of 121 hospitals, including 48 tertiary hospitals, 33 secondary hospitals, and 40 primary hospitals. The number of hospital health technicians is exploited to characterize the hospital supply. Additionally, community health service centers are grass-roots medical facilities and play a vital role in the Shenzhen medical system. Baidu Map POI data was implemented to crawl the city's community health service centers in 2018, and a total of 484 community health service centers were identified after data cleaning. Since the number of health technicians of each community health service center could not be explicitly extracted, the average number of health technicians of independent community health service centers in the *Shenzhen Health Statistical Record 2018* is evaluated to be 21, taken as the standard value for the unified assignment.

According to the *Shenzhen Medical Facilities Setting Plan (2016-2020)*, primary medical facilities include primary hospitals and community health service centers, considered as low-level medical facilities. Secondary hospitals and tertiary hospitals are also taken into account as high-level medical facilities. As demnstrated in Fig. 4, the distribution of the two levels of medical facilities in each administrative district and community of Shenzhen presents a specific aggregation.
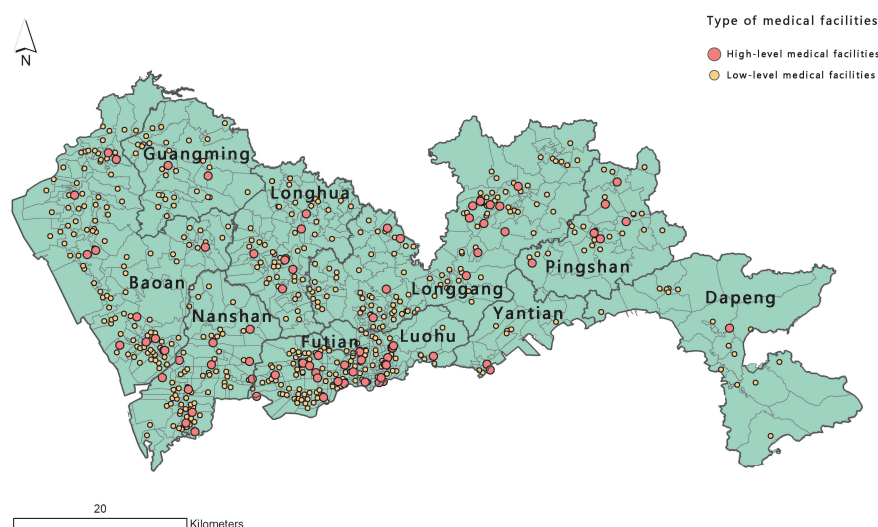

Figure 4. Distribution of medical facilities in Shenzhen (Data source: Information about Medical Facilities in Shenzhen. https://opendata.sz.gov.cn/; Baidu Map POI 2018).

The *Construction Standards for General Hospitals (2008)* stipulated that community medical facilities should be located in densely populated urban areas so that residents can reach them within a 15-minute walking time, and also combined with the setting of the 15-minute living circle, 15-minute walking time is considered as the effective service radius of low-level medical facilities. Bosanac, Parkinson, and Hall (1976) studied accessibility service radius. Instead of accepting the traditional distance as a measure of accessibility, they utilized the travel time as a new indicator and identified a 30-minute service standard using general hospitals in West Virginia as an example. Therefore, 30-minute driving time is taken as the effective service radius of high-level medical facilities.

In the next step, the road data are processed. The ArcGIS software is employed to process the topology of the acquired road data in Shenzhen, and the network analysis tool is exploited to construct a network

dataset, and then the new service area tool is employed to evaluate the service area of each level of medical facilities in the hierarchical road network. In this network dataset, various speeds are assigned according to the roads' levels. The *Annual Report on Traffic Development in Shenzhen 2011* indicates that the operating speed of roads in the city during the morning peak hour is 49km/h for expressways, 32.2km/h for trunk roads, 24km/h for secondary roads, and 25.9km/h for feeder roads. Due to the particularity of medical service, it is necessary to travel even during the morning peak hour. Therefore, the mentioned above speeds are utilized to assign to each road level while taking the urban pedestrian walking speed of 1.24m/s as the unified walking speed. These two data are appropriately combined to construct the network data set.

The primary population data is taken from the *Shenzhen Statistical Yearbook 2019*. Suppose that the statistical unit of the population like street/community can be directly utilized, then each unit could only exploit a point graph to characterize all its population during the assessment with error. Hence, a mathematical model is exploited to assign the statistical population data to residential buildings for enhancing the accuracy of the accessibility research. The residential buildings in Shenzhen are mainly divided into urban villages and general residential buildings. The population per square meter of urban villages and general residential buildings could be obtained by multiple regression of the data, then the population of general units could be allocated to each residential building.

Due to the discrepancies in the development of the inside and outside former Shenzhen SEZ, the population per square meter of these two areas are also different to a certain extent. To calculate the population per square meter of urban villages and general residential buildings, the inside and the outside former SEZ are analyzed separately. According to the community-based statistical population of Shenzhen in 2014, the community population in 2018 was calculated based on the population growth ratio of each district, then the predicted results are combined with the Shenzhen building census data in 2018 for multiple regression analysis. Herein, community population data is considered instead of the general district and street populations to provide more samples for regression analysis and making the results more accurate. The results of multiple regression analysis reveal a meaningful correlation between the population and the floor area of urban villages buildings and general residential buildings inside the former Shenzhen SEZ. The multiple correlation coefficient would be 0.99 (sig<0.0001), and the multiple regression equation is obtained as follows:

$$P=0.013 \times A_N+0.053 \times A_S+48 \quad (R^2)=0.997 \tag{7}$$

Additionally, there exists a notable correlation between the population and the floor area of urban villages and general residential buildings outside the former Shenzhen SEZ. The multiple correlation coefficient is 0.87 (sig<0.0001), and the multiple regression equation is stated by:

$$P=0.010 \times A_N+0.026 \times A_S+3479 \quad (R^2)=0.746 \tag{8}$$

where P denotes the predicted population, A_N represents the general residential buildings floor area, and A_S is the floor area of urban villages buildings. The population per square meter of urban villages buildings to general residential buildings inside and outside former Shenzhen SEZ is calculated to be 4.1 and 2.6, respectively. The population of each residential building is obtained by assigning the 2018 population data from the statistical yearbook of each district to the corresponding building census map at the same time.

In continuing the accessibility of medical facilities of each residential building could be rationally evalauted. The residential buildings in various areas could be screened based on the analysis requirements, and the overall accessibility of each area is obtained by applying Eq. (4). Since the community has been taken into account as the basic research unit, the accessibility of residential buildings in each community is summarized to assess its overall accessibility. At this step, the parameter n in Eq. (4) represents the number of residential buildings in each community. Further, the population

density of each community (see Fig. 5) is predicted based on the above residential building population data to assist in the analysis of accessibility results.
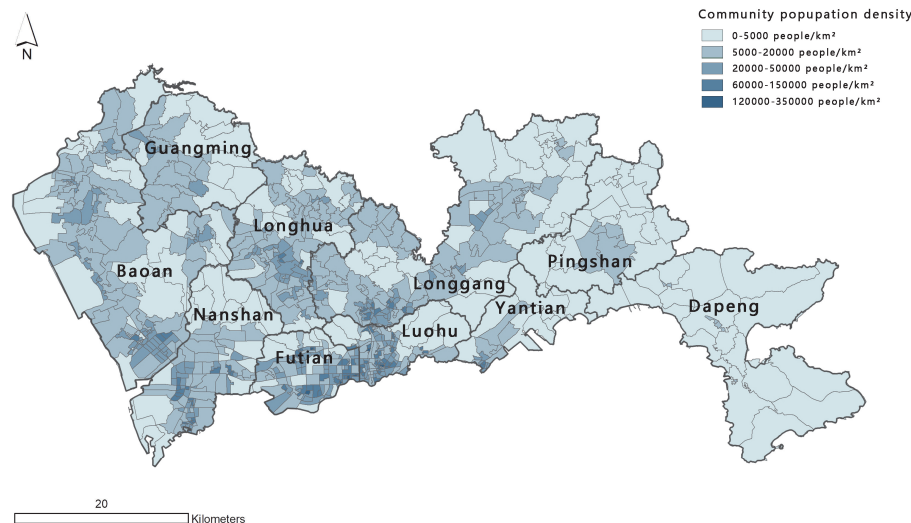

Figure 5. Shenzhen community population density.

4. Results

4.1. Accessibility of medical facilities

Accessibility per 100 people is employed as the results index, representing the number of health technicians available per 100 residents. For low-level medical facilities, the results have been demonstrated in Fig. 6. By combining this data with the community population density, it is indicated that the accessibility of communities with higher population density is mainly at a lower level, while the accessibility of communities close to the eastern administrative border of the city is mainly at a higher level. This fact is attributed to the constructions of community health service centers in Shenzhen are essentially designed based on community units, and for communities with higher population density, the number of patients that the community health service center has to take is on far exceeds its capacity, such as some communities placed in Baoan, Nanshan, and Luohu districts. In addition, some of the high population density communities still have high accessibility due to enough primary hospitals within them as a supplement, such as some communities in districts of Longhua, Longgang, and Futian. For communities close to the city's administrative border with a small population, the ratio of supply to demand is relatively large. The quality of services provided by low-level medical facilities available to community residents has been improved accordingly, and thereby, the accessibility is high.
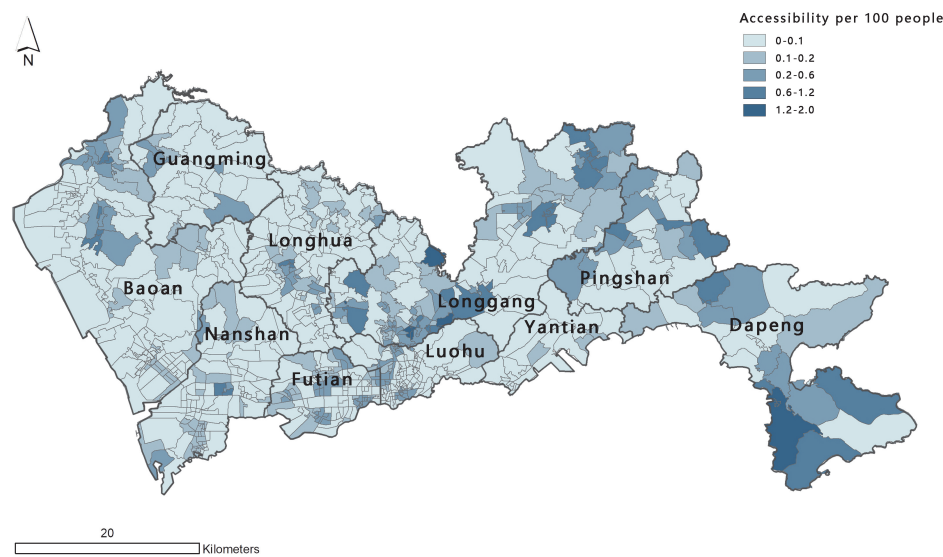
Figure 6. Accessibility of low-level medical facilities of the community.

For the investigation of high-level medical facilities, i.e., the accessibility of residents in each community to secondary and tertiary hospitals, the predicted results have been presented in Fig. 7. In contrast to the accessibility of low-level medical facilities, the communities with higher accessibility are mainly located in the city's central areas, while the accessibility of communities close to the city's administrative border is low. The data analysis reveals the following reasons: Since high-level medical facilities are concentrated in the central regions of the city with large service areas, the communities in the central areas can enjoy the high-quality services of numerous secondary and tertiary hospitals. For communities close to the city's administrative border, the accessibility is low because of the small number of hospitals and lower quality of medical services.
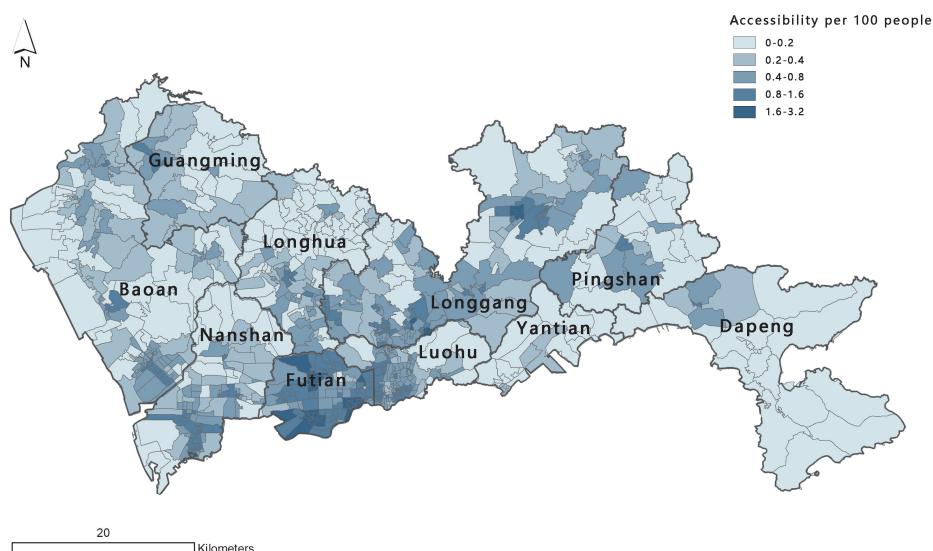

Figure 7. Accessibility of high-level medical facilities of the community.

Based on the hierarchical medical system, patients are required to consider referrals in seeking medical treatment. Also, each community should take into account both the accessibility of low-level and high-level medical facilities (i.e., the overall accessibility to medical facilities, see Fig. 8). According to the spatial location of the overall accessibility of medical facilities in Shenzhen, the areas with high accessibility are mostly concentrated in Longgang and Futian districts. Although the population density of Futin District is high, the uneven distribution of medical facilities gives it the most medical resources, so the overall accessibility is high. The regional center of Longgang District is located in its eastern part, which gathers excellent medical resources in the district and allows nearby residents to enjoy medical services conveniently. In contrast, residents in the western part of Longgang District can travel to the former SEZ to enjoy high-quality medical services, and the combination of these two provides Longgang District with highly overall accessibility.
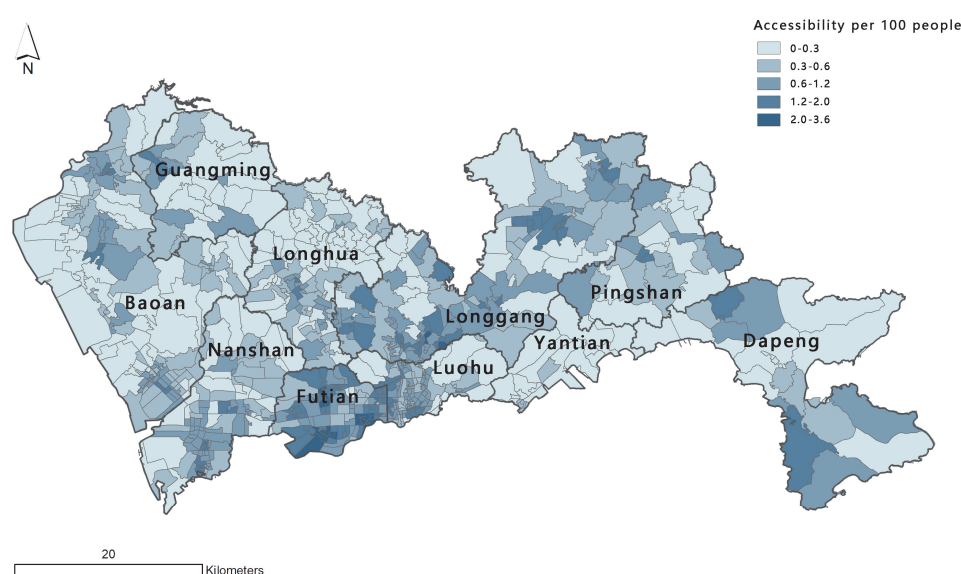

Figure 8. Overall accessibility of medical facilities of the community.

The overall accessibility of medical facilities varies widely in districts of Shenzhen (see Fig. 9) such that the districts inside the former SEZ have higher accessibility because of their leading development and well-developed infrastructures. For instance, Futian District has the highest accessibility among the ten districts of Shenzhen, and Nanshan and Luohu districts are close to the average accessibility of 0.66; nevertheless, Yantian District has the lowest accessibility due to its significant development in the port and tourism industry, and thereby, the distribution of medical facilities has been less paid attention. Among the districts outside the former SEZ, Longgang and Dapeng districts have near-average accessibility, while the others are generally below the average level. Both Baoan and Longhua districts have large population values, and Pingshan District lacks medical facilities, leading to a decline in overall accessibility.
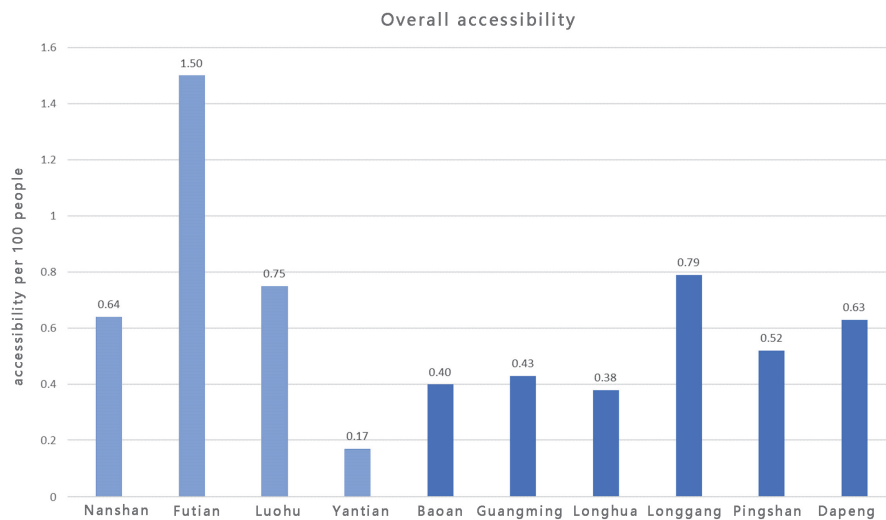
Figure 9. Overall accessibility of medical facilities of various districts.

The statistical of the spatial configuration analysis has been presented in Fig. 10. In the current situation in Shenzhen, controlling the referral rate at 80% can maximize the exploitation of medical facilities resources and leads to the best spatial configuration. Furthermore, high-level medical facilities require to perform duties for emergency treatment in response to significant public health emergencies, the corresponding medical resources are needed to maintain a certain degree of flexibility, and a patient allocation ratio of 70% referral rate could reserve resource flexibility of about 15% for high-level medical facilities. As a result, based on the current construction of medical facilities in Shenzhen, a referral rate of 70%-80% would be effective (i.e., most patients should be treated at high-level medical facilities). This issue indicates that the development of medical facilities in Shenzhen is uneven, with insufficient number and capacity of low-level facilities, resulting in patients' needs to be focused on high-level medical facilities.
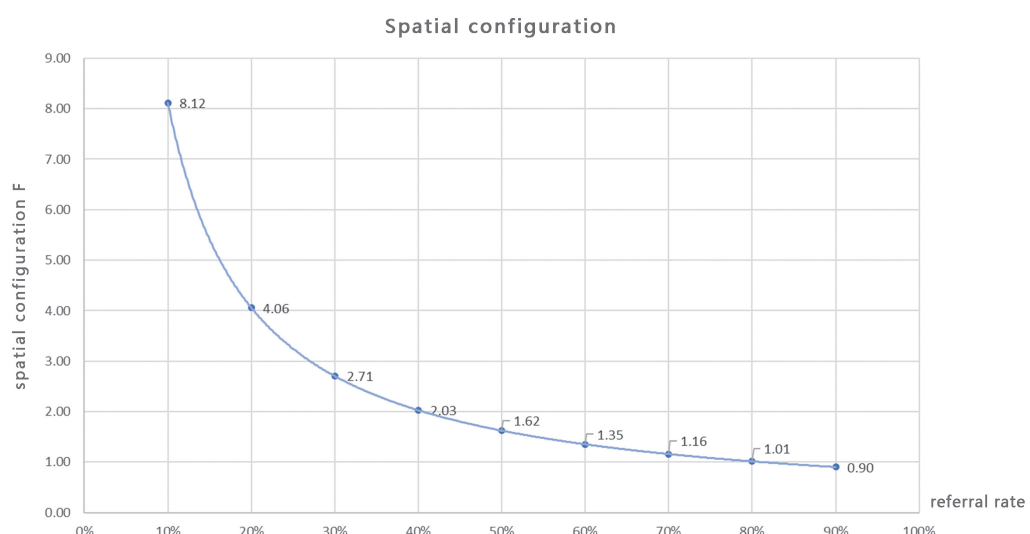

Figure 10. Spatial configuration in terms of the referral rate in Shenzhen.

4.2. Comparisons based on accessibility

Based on the performed scrutiny, the overall accessibility and optimal referral rate of medical facilities in Shenzhen are assessed. This part is aimed to exploit the mentioned above results to compare with those of various cities of China and abroad to discover the current deficiencies in the planning of medical facilities of Shenzhen and to guide the subsequent planning. Before proceeding in the comparison study, the index should be standardized. Since the index exploited to characterize the supply of a medical facility is the total number of health technicians, the resulting accessibility per 100 people can be displayed as the number of health technicians per 100 people. The commonly exploited index in China and abroad is the number of physicians per 1,000 people, and physicians are part of the health technicians; hence, the index should be appropriately modified. According to the *Shenzhen Health Statistical Record 2018*, physicians are estimated to be 38.8% of health technicians. Suppose the average overall accessibility per 100 people in Shenzhen (0.66) from the research results should be modified by this ratio. In that case, the overall accessibility per 1,000 people is 2.56. This fact represents that the number of physicians available per 1,000 residents would be 2.56, which is close to the number of physicians per 1,000 people released in 2018 by the *Shenzhen Health and Sanitation Commission* of 2.79. As a result, the results of all subsequent comparisons should be accordingly modified on the basis of this ratio.

According to the health data released by the *National Bureau of Statistics*, the number of physicians per 1,000 people in China was 2.6 in 2018, with 4.0 in cities and 1.8 in rural areas. In Shenzhen, the number of physicians per 1,000 people is slightly higher than that of the national average but well below the urban average level. The number of physicians per 1,000 people in the remaining first-tier cities in China in 2018 was 4.6 in Beijing, 3.6 in Guangzhou, and 3.0 in Shanghai. As is seen, all these levels are higher than that of Shenzhen, which clearly indicates that the current medical capacity of Shenzhen is lagging behind its economic development.

According to information published by the *World Bank WDI database*, the number of physicians per 1,000 people in middle-income countries was 1.3 in 2015, while in high-income countries was 3.0, and only Shenzhen does not meet this standard among the first-tier cities in China. Regarding high-income countries such as Germany, Czech Republic, Sweden, and Switzerland, where health cares have been well developed, the number of physicians per 1,000 people is a slightly higher than 4.0.

Based on the comparison of the number of physicians per 1,000 people between Shenzhen and different standards and cities in China and abroad, all communities in Shenzhen are divided into five categories and given various development goals to set the priority of medical capacity improvement, guiding future medical facility development planning (see Fig. 11, Table. 1). The first category is communities with transformed accessibility below 1.3. These communities are close to the city's administrative borders and are relatively underdeveloped, resulting in inadequate medical facilities. Generally, these communities fail to meet the international average level of middle-income countries and the domestic average level of rural areas. They are the communities most in need of updating and will be the first batch of targets for updating to effectively make up for the deficiencies of medical capacity in Shenzhen. The second category is communities with transformed accessibility below 2.6. The number of physicians per 1,000 people in these communities is lower than the average level in Shenzhen and China, and there is an urgent need to increase the construction of medical facilities and investment in medical staff. They are located mainly near the district-to-district borders as the second batch of upgrading targets. The above two categories of communities account for 65% of the population of Shenzhen, indicating that the majority of residents currently have insufficient medical resources available to them. The third category is communities with transformed accessibility below 3.0. These communities will target Shanghai and high-income countries as the third batch of upgrading targets to support Shenzhen continue medical development and maintain a reasonable level. The fourth category is communities with transformed accessibility below 4.0. These communities will target physicians per 1,000 people in China's

cities and excellent international high-income countries as the ultimate demonstration targets. The fifth category is communities that have already reached international excellence standards and do not require additional investment for the time being. These communities are commonly concentrated in the Futian District and the developed areas in the rest of the districts, accounting for about 20% of the total population of Shenzhen.
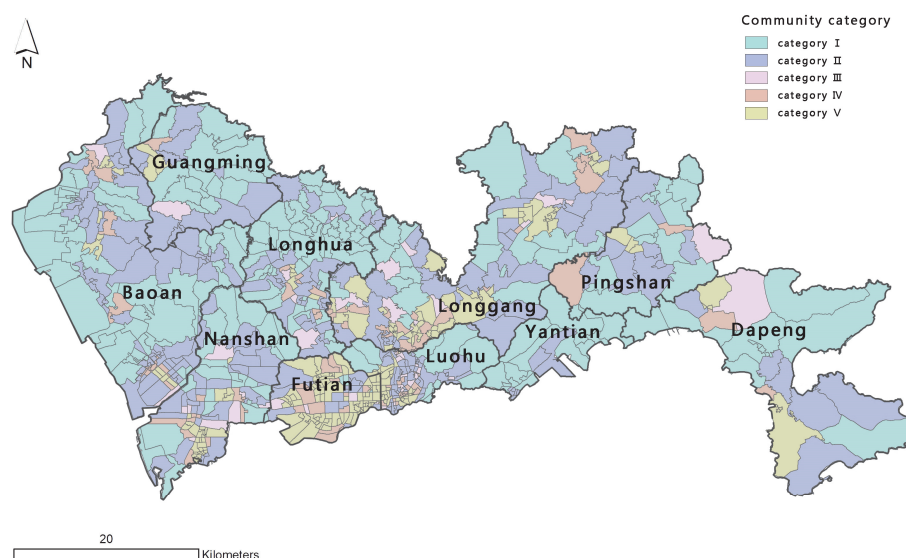

Figure 11. Shenzhen community categories on medical capacity improvement.

Table 1. Statistics of Shenzhen community categories on medical capacity improvement

Category	Number of communities	Population	Population share	Priority
I	209	3935305	29.43%	highest
II	255	4791394	35.83%	high
III	41	737310	5.51%	medium
IV	80	1125021	8.41%	low
V	196	2782401	20.81%	lowest

Many countries are currently controlling the referral rate at a low level. For example, the referral rate in Russia is generally 25%-30%, while the referrals rates in the United States, the United Kingdom, and the Netherlands are controlled at lower than 10% (Zhou, 2015) because of their essential primary care resources. For instance, the US has a group physician system and motivations for medical students who choose community employment. For this purpose, a homogeneous medical education is provided to allow community doctors to have the same level of care as senior hospital doctors (Stange et al., 1998; Beck, 2004). Through these measures, the investment in primary care resources grows to help patients resolve most of their illnesses in the community without going to the hospital. The current situation in Shenzhen includes problems such as an incomplete referral system and the limited medical capacity of community health service centers. This issue results in a low trust of patients, such that the vast majority of patients preferring to go directly to hospitals and only a few being referred through initial diagnosis by community health service centers. To conquer these difficulties, first of all, the capacity of community health service centers should be appropriately improved and the investment in primary health care resources to build patients' trust should be enhanced. Further, it is necessary to establish a reasonable

system to limit the treatments of minor diseases in senior hospitals, evacuate these treatments in senior hospitals to community health service centers, support the specialization and refinement of senior hospitals, and enhance the comprehensiveness and universality of community health service centers. This restructuring to achieve a new structure of the medical system will lead to the overall growth of medical services in Shenzhen, reducing future referral rates and releasing pressure on senior hospitals to respond to public health emergencies.

5. Conclusions

The implementation of the hierarchical medical system can better designate medical facility resources. The main findings of this research are: 1) For low-level medical facilities such as community health service centers, not only they should be set up on a community basis during planning, but they are also required to consider each community's population in order to provide matching medical resources. 2) For residents in the areas close to the city's administrative borders, due to the lack of high-quality secondary and tertiary hospitals, their accessibility to high-level medical facilities is fairly low, and planners should take into account the demands of these areas in future planning. 3) The overall development of medical facilities in Shenzhen is at the back of the first-tier cities in China, and there is an irregular development of medical facilities between the administrative districts and communities. Through comparison with domestic and international cities, communities are divided into five categories for categorized policy based on the accessibility as a crucial indicator to accurately enhance the medical services capacity. 4) According to the current construction of medical facilities in Shenzhen, controlling the referral rate at about 70%-80% yields the best spatial configuration for a balanced distribution of medical resources. This fact indicates that the current role of low-level medical facilities in Shenzhen is in an underdeveloped state. Through a comparative scrutiny based on referral rates, the allocation of medical resources and adjustment of the medical system should be carried out. Enhancing the treatment capacity of community health service centers and the evacuation of minor diseases in senior hospitals will provide an overall advancement in Shenzhen's medical capacity.

The present research has the following shortcomings: First, the calculations of the supply capacity of medical facilities is not complete. The current research only considers the number of health technicians in medical facilities, but the supply capacity of medical facilities is also related to the number of hospital beds and floor space, which cannot be enhanced because of the lack of data. Secondly, the employed referral mode in the current research is one-way referral mode (i.e., from low-level medical facilities to high-level medical facilities), and the accessibility of medical facilities in the case of two-way referral has not been considered, which involves more complex data and methods, and further research works are needed to examine this deeply. Thirdly, there exists a lack of research on spatial equality. This factor is a crucial indicator for evaluating the distribution of public facilities and focusing on the needs of disadvantaged groups, which can effectively assist urban planners to identify under-provided areas and give advice to allocate public facilities.

6. Acknowledgements

7. References

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