Analysis and Optimization of Community Health Service Facility Layout in Beijing in Relation to the Distribution of the Elderly Population

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Abstract. The widespread and balanced distribution of health and medical services is a core element in constructing a fair health service system. Moreover，elderly population is the main population of basic community healthy patient. Using Beijing as a case study, this research employs Geographic Information Systems (GIS) to integrate the minimal facility site model and minimal impedance model, aiming to delve deeply into the locational optimization design of community health service facilities across Beijing. Based on the distribution of the elderly population density， the research methodology encompasses data collection, an assessment of the existing medical development status, and GIS analysis, offering a comprehensive understanding of the distribution and locational characteristics of community health service centers, and further examining the relationship between their service coverage and community needs. By focusing on the Dongcheng and Xicheng districts as specific cases, this study proposes optimization recommendations concerning the siting and quantity of community health service centers in Beijing, with the hope of providing insights for promoting balanced distribution and accessibility of community medical institutions in the city.

Keyword . Community Health Service Center， Medical Resource Optimization，Medical Service， Accessibility，GIS Analysis，Minimized Impedance Model

1 Introduction

In the "Healthy China 2030" Plan Outline, it is explicitly stated that China should ensure that the basic medical and health resources in counties and cities are rationally allocated based on the permanent population and service radius, aiming to achieve equal basic medical and health services for all citizens[1]. According to an article published in Counsellors office of Shanghai Municipal People's Government on March 16, 2015, From 2010 to 2032, the proportion of the elderly population aged 60 and above in China is expected to double, reaching 26.69%, with an average increase of one percentage point every two years. By 2050, the proportion of the elderly population is projected to reach 34.78%[2]. The current distribution of medical, health, and elderly care resources across the country remains unbalanced, struggling to fully meet the health needs of urban and rural residents. Deborah, O.M.L. et al. (2018) have pointed that in societies with a significant elderly population, accessible primary healthcare is crucial for national healthcare, with older persons as the primary users of community health service centers. Faced

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with China's increasingly severe aging population and changes in fertility, and in order to align with the development challenges and policy orientations of the new era, we must prioritize the accessibility and equity of medical and health services. Specifically, the site selection, expansion direction, and quantity settings of community health service centers play a pivotal role in ensuring a balanced distribution of basic medical resources in Beijing.

Humei, et al. (2023) studied a comparative exploration of the overall level of equity, spatial fairness patterns, and spatial interconnectivity[4]. However, it does not offer optimization strategies for spatial accessibility, equity, and linkage in regions with existing disparities, nor does it provide guidance for the construction of cities with resilient health systems. An analysis was conducted on the equilibrium of medical facility distribution within the secondary healthcare system of Beijing's six urban districts[5]. In response to population needs, the study proposed directional transformations between hospitals of various levels and secondary hospitals across different regions[5]. Hongguo R. et al. (2022) utilized the 15-minute health service radius as the minimal impedance factor, an impedance model was formulated. The study attempted to augment the medical system coverage in Handan city by increasing the number of hospitals at various levels[6]. This paper can draw upon the methodology of the study, with a focus on aging communities, and endeavor to achieve complete coverage by adding primary healthcare institutions. Utilizing Guangzhou taxi data, Yimin C. et al.(2022) comprehensively describes the city's healthcare facilities and conducts an in-depth analysis of healthcare accessibility through a gravity model. The study identifies a significant spatial imbalance in healthcare facility planning, with suburban hospitals having lower accessibility compared to city center hospitals, despite an overall concentric accessibility pattern[7]. However, the study does not provide solutions for addressing these planning inequalities or examine community hospitals in areas with similar accessibility but differ a more equitable and comprehensive community healthcent elderly population densities.Subsequent investigations reveal that urban areas have substantially higher elderly population densities compared to suburban areas. Thus, this study aims to explore strategies for mitigating these spatial planning disparities, with the goal of establishingare service system. Hu,S et al.(2023) measure accessibility of Community Health Service Facility using POI、OSM and WorldPop data[8]. Dong, E. et al.(2021) argued that regional disparities between urban and rural areas, as well as inequalities in healthcare facility resources, continue to persist[9]. Khakh, A. K. K.et al.(2019) discuss the achievement of universal access to primary healthcare in Canada, but points out the spatial inequality in healthcare due to the uneven distribution of primary healthcare facilities and the population. The article suggests addressing this issue by advocating for the construction of new primary healthcare facilities in areas with low accessibility[10]. Furthermore, our analysis focuses on a city where accessibility is relatively easy to achieve, and we examine the relationship between the distribution of a high-density elderly population and the potential for new spatial developments. This analysis raises questions about density inequality, which could be addressed by improving residential areas with high-density elderly populations in the city and constructing new medical clinics.

2 Study Area and Research Methodology

2.1Scope of Study

Beijing encompasses a vast administrative area, consisting of sixteen districts, each possessing distinct characteristics and current medical service conditions. Based on our research data (as illustrated in Table 1), we can discern the specifics of each district in Beijing. For instance, Xicheng and Dongcheng, the heart of the city, have populations of 1.104 million and 708,000, respectively, boasting 51 and 42 neighborhood communities. They house 15 and 17 primary healthcare facilities respectively, with other comprehensive medical facilities numbering at 263 and 177. Chaoyang District, a commercial and cultural hub, has the largest population of 4.65 million and encompasses 344.9 neighborhood communities. It possesses 22 primary healthcare facilities and a whopping 627 comprehensive educational and medical facilities. Haidian District, a major concentration of technology and education, is home to 4.31 million people and has 313 neighborhood communities. This district features 51 community health service centers and another 209 primary medical service stations. Moreover, districts beyond the central six, such as Changping, Daxing, and Shunyi, also have substantial medical service facilities. For example, Changping has a population of 2.27 million and encompasses 1342 neighborhood communities. It boasts 23 community health service centers and an additional 327 primary medical service stations.

Table 1. Overview and Medical Profile of Beijing's Six Central Districts.

	Area (km^2)	Population (in ten thousands)	Number of Streets	Number of Communities	Districts	Towns	Villages	Townships	Community Health Service Centers	Community Health Service Stations	Village Health Clinics
Xicheng District	51	110.4	15	263	-	-	-	-	15	77	-
Dongcheng District	42	70.8	17	177	-	-	-	-	7	47	-
Chaoyang District	465	344.9	22	627	-	-	-	-	52	224	-
Haidian District	431	313	28	584	-	-	-	-	51	209	-
Fengtai District	306	201.5	21	399	-	-	-	-	22	130	-
Shijingshan District	84	56.6	10	133	-	-	-	-	10	39	-
Changping District	1342	227	8	86	4	10	-	-	23	119	208
Daxing District	1036	199.5	5	87	5	9	-	-	21	124	-
Shunyi District	1020	132.6	6	127	-	19	426	-	26	165	-
Fangshan District	1995	131.3	11	154	-	-	-	-	25	175	-
Mentougou District	1448	39.6	4	120	1	8	181	-	11	20	-
Tongzhou District	906	184.3	11	175	-	10	-	1	22	98	-
Yanqing District	1995	34.6	12	47	-	12	-	-	18	54	-
Miyun District	2226	52.7	2	29	-	17	-	1	19	-	388

Pinggu District	948	45.73	2	37	-	14	272	2	18	118	-
Huairou District	2123	44.1	-	35	-	-	284	-	16	52	-
Total	1385.35	1098.8	113	2183	10	99	1163	4	157	726	596

Outside of Beijing's six urban districts, population density, lifestyle characteristics, and community features differ significantly from the central six. These outlying areas are classified into townships rather than urban communities, resulting in health facilities designed as township health centers, distinct from the urban population distribution and geographical conditions. This leads to a difference between the primary health care systems of the areas outside the six urban districts of Beijing and the urban health service system. Tailored optimization solutions must be proposed after analyzing the actual situation. The six urban districts of Beijing cover an area of about 1385km², including 113 streets and 2183 communities, with a population of approximately 10.988 million. These districts are primary regions of aging population in Beijing. The elderly tend to require more basic community medical facilities. Concentrating most of the city's public facilities, these districts have the densest population and construction in Beijing. Given the uniform basic medical system, numerous residential communities, and a higher aging population in the old urban areas, this research focuses on the six urban districts: Xicheng, Dongcheng, Chaoyang, Haidian, Fengtai, and Shijingshan. According to the "Beijing Aging Business Development Report (2021)" released by Beijing's Aging Office and the Aging Association, among the 16 districts in the city, the two with the highest degree of aging are Dongcheng and Xicheng. Liang Liping, the deputy director of the Chaoyangmen Community Health Service Center, stated that the daily outpatient volume of the center and its stations is five to six hundred people, with over 80% being the elderly. The Beijing Municipal Health Commission's Aging Health Department reported that in the past five years, community health service institutions have provided treatment services to the elderly an average of 35.95 million times annually, accounting for 55.43% of the total treatments, making the elderly the main service group. In 2021, 3.91 million health records were established for elderly individuals aged 60 and above in the city's community health service institutions, accounting for 91% of the total elderly population of that age range. Therefore, this paper will focus on optimizing the number of facilities in Dongcheng and Xicheng, where the elderly population is denser.

2.2 Research Methodology

2.2.1Data Sources

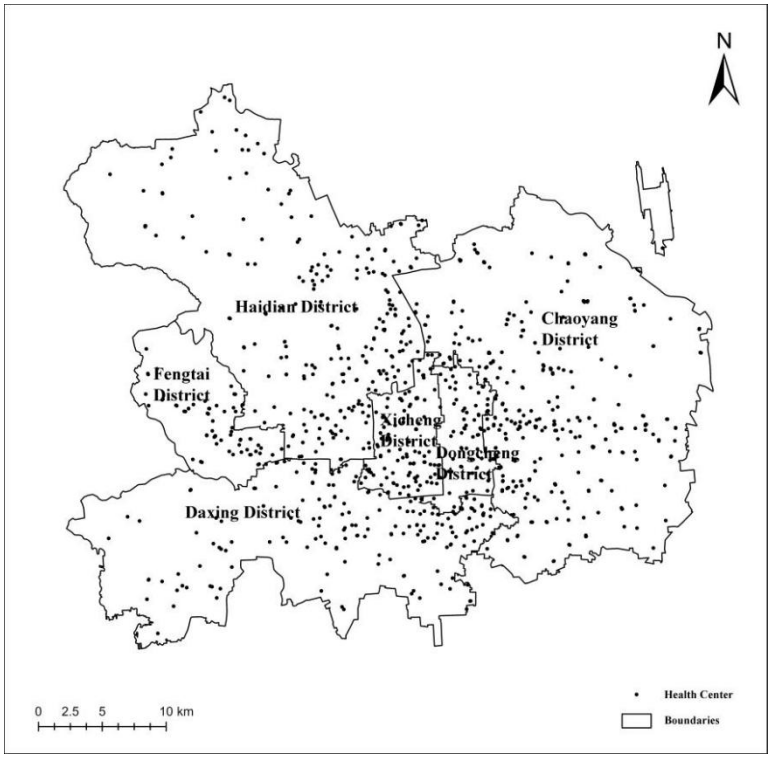
Beijing, as the capital of China, boasts a vast population and a complex urban structure, with the six central districts being the most densely populated and active areas. In recent years, with the advancement of urbanization, community health services have increasingly garnered attention. To better provide services and understand the current situation, the author chose the 2,183 communities within the six central districts of Beijing as the primary subjects of this study, with a particular focus on their community health service centers.

To ensure the accuracy and scientific rigor of the data, all research data were sourced from authoritative institutions. The vector files delineating administrative boundaries were obtained from the Resource and Environment Data Center, a center renowned for the professionalism and accuracy of its data and trusted by many researchers. To accurately represent the geographical locations of each community health service center, we collected original data

provided by the Beijing Health Commission and pinpointed these locations using Google Maps. Utilizing GIS technology, we conducted an in-depth analysis and processing of this data, ultimately producing a distribution map of medical facilities, as depicted in Figure 1.

Data regarding roads and residential areas were sourced from the National Earth Science System Data Center, a hub known for its comprehensive and scientific data, offering a solid foundation for our research. To obtain a precise grasp of the population in each community, we employed the latest data from the 2022 Seventh National Population Census. Details like the number of streets and communities were sourced from the WeChat public account "Population Database", known for its timely updates and providing timely and accurate data support for our research.

The current status and medical situation of the communities in Beijing's six central districts are crucial to this study. Aiming to provide valuable insights for policymakers and the general public, the author carried out thorough analyses and summaries based on the aforementioned datasets. Table 1 lists these detailed data and conclusions in-depth. Through this research, we hope to offer robust data support and references for enhancing community health services and informing the decisions of policymakers.



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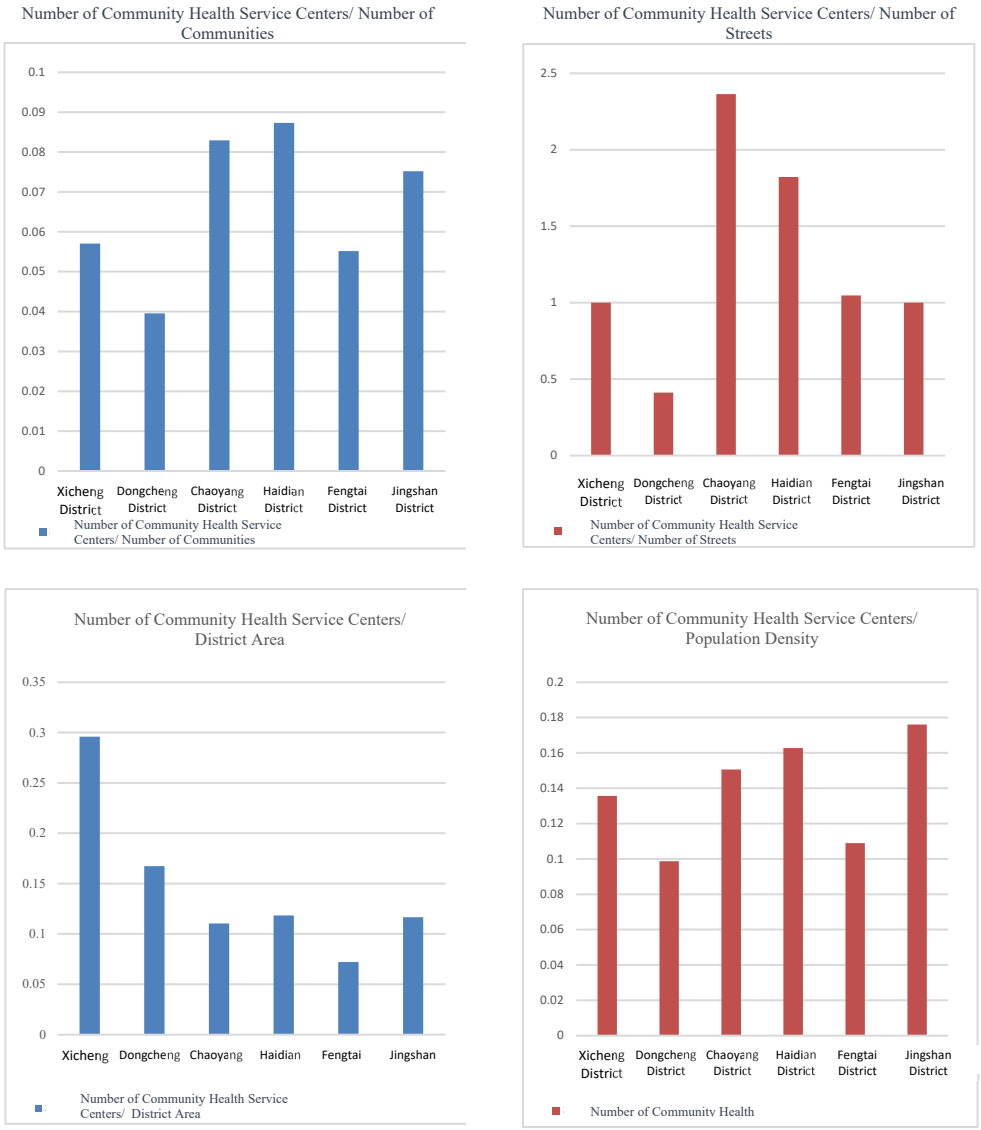

Fig 2. Relationship between Community Health Service Facilities in the Six Urban Districts and Community, Streets, Administrative Area Size, and Population Density.（ Community Health Service Facilities data from: https://map.beijing.gov.cn/category?categoryId=sqwsfwjg. Other data from Beijing municipal Bureau of Statistic:http://www.bjstats.gov.cn/）

2.2.2Analytical Methodology

This study is primarily divided into two pivotal sections, delving deeply into the optimization of the community health service facility layout in Beijing's urban core districts (known as "City Six Districts").

Firstly, we adopted a comprehensive methodology. The research initially centered on data processing and integration. We collected road network data, community health service facility location data, and administrative district delineation data, which were then imported into the ArcGIS software. This step laid the groundwork for subsequent spatial analysis and model application. With these datasets, our objective was to determine the actual service range of community health service facilities in the city. To this end, centered on the locations of the community health service facilities, we established a buffer based on a 15-minute living circle. Using the buffer analysis method in GIS, we successfully ascertained the radii of each community health service facility, granting us deeper insights into the coverage proportions of health service facilities in various areas.

Subsequently, we undertook optimization of the existing facility layout. Initially, we constructed a new location-allocation model in the GIS software. Our optimization goal was made clear: adjustments would be based on the elderly population density of each community. Specifically, we established a grid matrix at 200-meter intervals. For each point in this matrix, its inclusion in the model was determined based on the presence of an elderly population within its 100m x 100m radius. If a point lacked an elderly populace within its radius, it would be excluded from the model. This implied that these locales did not necessitate linkage with primary community medical centers. Following this, for the Dongcheng and Xicheng districts, we considered the walkable distances within their inner streets and the distribution of the elderly, attributing appropriate weights. By utilizing a minimum resistance model, we derived an optimization scheme, clarifying the positions and quantity of facilities that need to be added.

Not only does this research provide a well-defined methodological framework, but it also offers significant references for optimizing the layout of community health service facilities in practical applications. Such optimization will aid in the rational allocation of resources, cater more effectively to residents' medical needs, and furnish robust support for urban planning and public health management.

3 Current Situation Analysis: Analysis of the Existing Layout of Community Health Service Facilities.

3.1Analysis of the Number of Community Health Service Facilities in Various Regions.

From Figure 2, we can clearly observe the distribution disparities of various indicators within the "City Six Districts." In the graph representing the "Ratio of Community Health Service Facilities to Communities," both Chaoyang and Haidian districts display a higher ratio, suggesting that in these two districts, each community has a greater number of corresponding health service facilities. Conversely, the Dongcheng district has the lowest ratio, further attesting to the sparsity of its community health service facilities.

Turning to the graph illustrating the "Ratio of Community Health Service Facilities to Area," it's evident that the Xicheng district possesses the highest value. This suggests that although Xicheng might have a relatively smaller area, it boasts the most abundant number of health service facilities. Dongcheng district's value is the next highest, albeit with a notable gap when compared to Xicheng. Other regions, like Fengtai and Shijingshan districts, have lower ratios, indicating fewer health facilities relative to their respective areas.

In the graph of the "Ratio of Community Health Service Facilities to Residents," Shijingshan district emerges with the highest value. This suggests that the proportion of permanent residents to health facilities is relatively high in this district, providing more medical facilities to its inhabitants. Meanwhile, Chaoyang, Haidian, and Xicheng districts all display similar values, all slightly below Shijingshan. Both Dongcheng and Fengtai districts have the lowest values, indicating that these two districts have the fewest health facilities per resident.

Lastly, the "Ratio of Community Health Service Facilities to Population" graph reveals that Shijingshan has the highest ratio. This implies that residents of Shijingshan have access to a larger number of medical facilities relative to its total population. Chaoyang, Haidian, and Xicheng districts possess similar ratios, all positioned in the middle range. Conversely, Dongcheng and Fengtai districts have the lowest ratios.

Based on the above analysis, Dongcheng district has the fewest community health service institutions among all districts, placing it in a relatively lagging position. It represents an area of weakness in the community medical infrastructure within the City Six Districts. While some regions might boast a higher number of community health service facilities, there are still disparities in actual medical service coverage when compared to factors such as area and resident population. The community medical facilities in Beijing's City Six Districts demonstrate imbalanced development. Decisions on whether to increase or decrease facilities should be based on further GIS buffer analyses to address areas with medical insufficiencies and reduce wastage of medical personnel and resources.

3.2Coverage of Community Health Service Facilities in Each District.

In the "Technical Guide for Community Living Circle Planning" , community services are categorized into three types: basic guarantees, quality improvement, and distinctive guidance. Community health service facilities are deemed as a fundamental guarantee service element for the 15-minute tier, configured based on streets (towns)[11]. Each street (town) can approximately be considered as a 15-minute living circle. Community health service stations, on the other hand, are quality improvement service elements for the 5-10 minute tier, supplementing areas that are hard for community health service facilities to reach. Thus, their planning and construction should thoroughly consider the actual needs of residents, providing them with convenient, efficient, and high-quality services. Based on the 15-minute living circle proposed in the "Urban Residential Area Planning and Design Standards", it should serve 50,000-100,000 people, with a service radius of 800-1100m [11]. This implies that residents within this range can easily access the services of community health facilities. This article chooses a service radius of 1000m based on these standards, which is a reasonable range that both ensures service efficiency and meets resident demands.

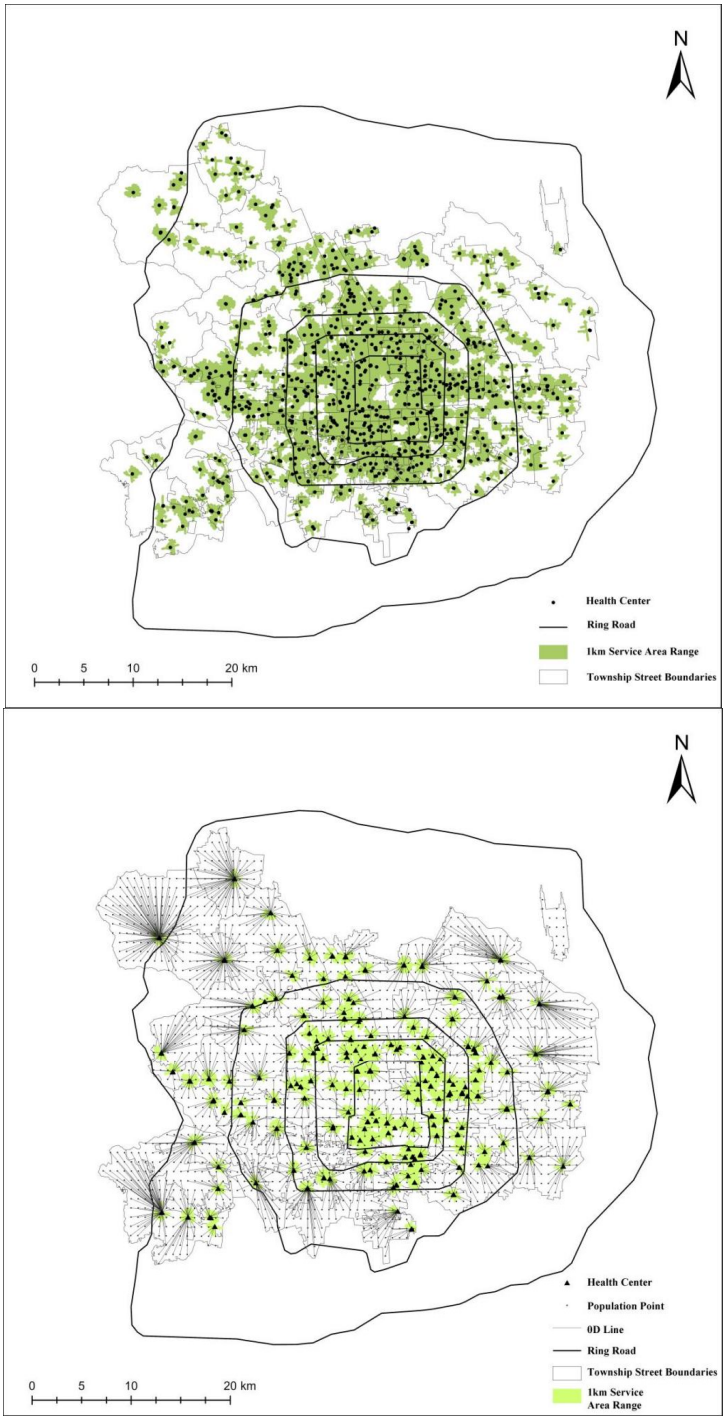

Figure 3. Distribution and Service Area Map of Community Health Service Facilities in Beijing.

From Figure 3, it is evident that community health service facilities in Beijing are primarily concentrated in the central urban areas. These two maps visually depict the distribution characteristics of community health service facilities and their relationship with different urban districts. Within the study scope, the land area that meets the 15-minute service radius of community health service facilities is approximately 5963km². The remaining areas reveal gaps, indicating regions not covered by the service radius of community health facilities. Each administrative district that satisfies the 15-minute service radius constitutes about 36.34% of the area. Moving from the urban center towards the city's outskirts, the number and density of health service facilities decrease, indicating an uneven distribution of primary medical facilities. In terms of facility distribution, the central districts of Beijing, namely Dongcheng and Xicheng, are denser compared to other districts. The closer to the city center, the more comprehensive the community medical service facilities. However, districts like Haidian, Chaoyang, Daxing, and Fengtai, which are farther from the city center, lack adequate community health service facilities. The infrastructure for basic medical services is not as developed as in the central districts. This implies that residents living on the city's periphery or in areas with limited transportation access may face challenges accessing primary medical services. This disparity in service distribution is a pressing concern in urban planning and development. To ensure that all residents can conveniently access basic medical services, urban planners and policymakers need to consider optimizing the existing layout of community health service facilities or establishing new ones in underserved areas.

3.3Distribution of the Elderly Population in Dongcheng and Xicheng Districts of Beijing.

Based on the heatmap (Figure 4) illustrating the distribution of the elderly population in the Dongcheng and Xicheng districts of Beijing, we observe distinct high-density clusters of elderly residents in the north-central parts of both districts. The southeast and southwest sections also exhibit pronounced high-density pockets of elderly residents. These red zones could be related to historical, cultural, and early urban planning factors, representing older residential areas or areas with unique community characteristics. Conversely, the green areas on the map, indicating a sparse elderly population, might be newly developed zones in recent years, or primarily commercial and office spaces that are less suitable for elderly residence. Given that the elderly often require more frequent medical attention and regular check-ups, these high-density red zones should be prioritized for community health services. In recent years, there has been a growing focus on utilizing satellite imagery and open geospatial data to understand large-scale sustainable development outcomes. Health and education are critical domains of the United Nations' Sustainable Development Goals (SDGs). However, existing research on the accessibility of corresponding services has primarily emphasized detailed but small-scale studies. This implies a lack of accessibility metrics for large-scale quantitative assessments. To address this deficiency, (Hu, S.&Zhao, R., (2023) employed data analysis and heatmap techniques to assess the accessibility of community healthcare facilities. However, when juxtaposing this information against the earlier distribution of community health services, it's evident that the current health facilities do not adequately cater to these densely-populated elderly zones. This misalignment might hinder some senior citizens from accessing timely and convenient medical assistance when needed. Considering the potentially limited mobility of the elderly, there's a strong recommendation to increase community health service facilities in these red, high-density areas. We formulated our model strategy to comprehend the conceptual modeling processes in the utilization of simulation optimization for facility layout design[12].

This strategy would not only provide more convenient medical services for the elderly but could also alleviate the strain on central health facilities. In future urban planning and development, taking into account the distribution and needs of the elderly population is crucial. To ensure all citizens, especially the elderly, have access to high-quality medical services, governments and relevant authorities should adjust and optimize the layout of healthcare facilities based on the actual distribution of the elderly population.

4 Optimization Solutions: Strategies for Improving the Layout of Community Health Service Facilities.

This study employs Geographic Information System (GIS) technology to simulate the layout and distribution of community health service facilities. Within this framework, we applied two primary models: the Minimum Facility Site Model and the Minimum Impedance Model. The Minimum Facility Site Model is a strategy that seeks the optimal service facility points that can cater to the maximum number of users within a designated service radius. This implies that, through this model, we can ensure that within a specific area, the number of service facilities is minimized while still meeting the basic needs of all users[3]. This approach not only effectively reduces construction and operational costs but also ensures the maximized utilization of resources. On the other hand, the Minimum Impedance Model primarily considers the impact of facility layout on people's travel distances. Using this model, we can determine an optimal facility layout that minimizes the average distance for all users to reach their nearest service facility. This not only enhances the convenience of the service, reducing travel costs and time for individuals, but also encourages more frequent use of the service, thus elevating the overall community health standards.

By integrating these two models, this study offers a comprehensive and detailed analytical framework, guiding the effective layout and optimization of community health service facilities to meet the needs of a vast array of users, ensuring rational resource allocation and maximization of utility.

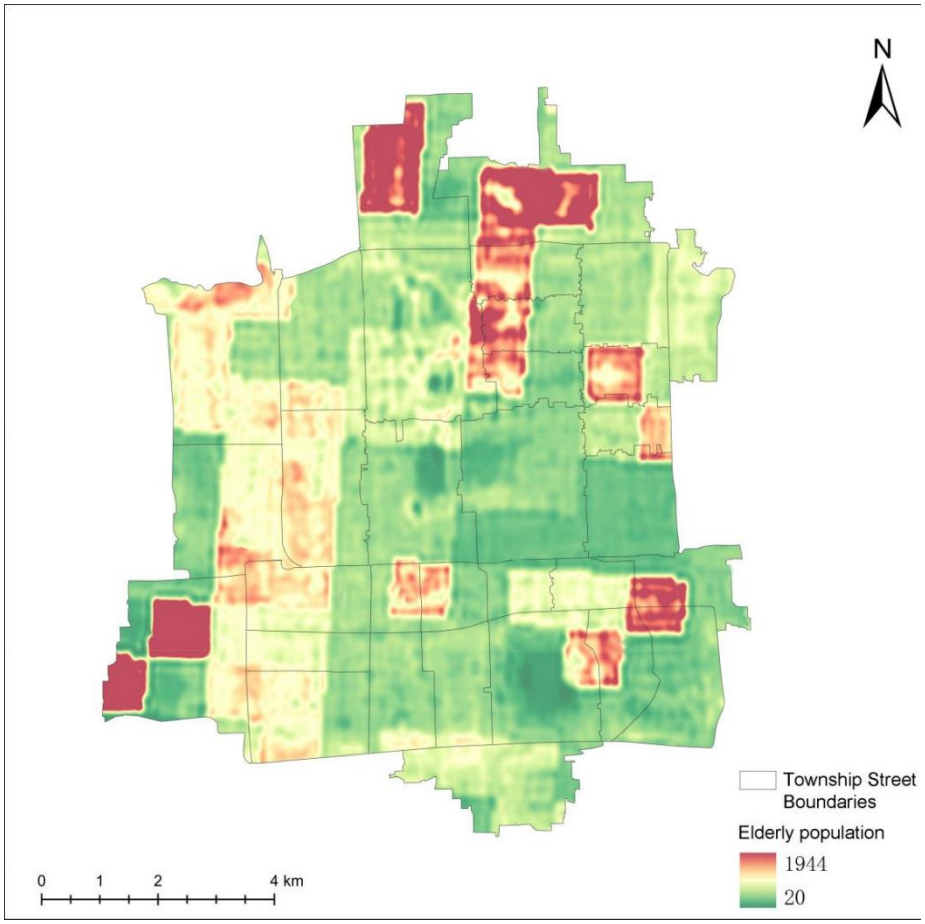

Fig 4. Heatmap of the Distribution of the Elderly Population in the East and West Districts of Beijing.

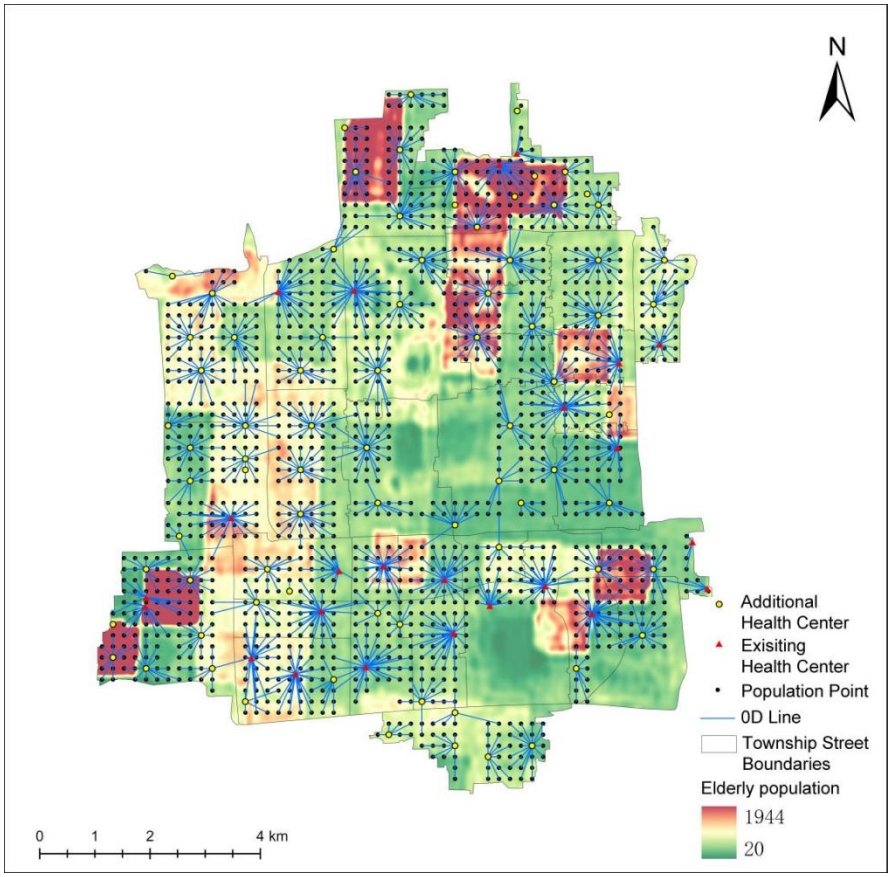

Fig 5. Analysis Diagram of Minimized Facility Location and Minimized Resistance Models for Community Health Services in the East and West Districts of Beijing.

Referring to the previously mentioned data on population density and district size, we aim to investigate the relationship between the imbalance in the distribution of community hospitals and the density of the elderly population. Subsequently, we conducted an analysis using the minimization location-allocation model for community healthcare service facilities in the eastern and western regions of Beijing. This analysis aimed to explore the distribution of medical service facilities within the city. The study revealed that, in certain areas, healthcare service facilities suffer from issue, namely, excessively dense distribution. The findings revealed that health service facilities in some areas are located too closely to each other. When two primary healthcare facilities cover the same community, it can result in a redundant wastage of medical resources. Thus, after evaluating, one of the community health service facilities can be discontinued. Further simulations with the model showed that even after discontinuation, the health service facilities still adequately meet all the medical needs of that area, effectively reducing the financial strain on healthcare.

According to calculations from the Minimum Facility Site Model and the Minimum Impedance Model, there's a recommendation to establish an additional 24 community health service

facilities, as illustrated in Figure 5. The newly proposed locations were initially areas where existing health service facilities were too far for residents to access on foot, posing a particular challenge for the elderly. The system in community health service facilities typically operates on on-site registration, and elderly individuals seldom use mobile apps for appointment bookings. If they can't register upon arrival or need a follow-up visit for blood tests, the extended travel distances can become significant hindrances, failing to meet their basic medical needs promptly. Thus, it's advisable to add these facilities to alleviate the pressure on nearby health service facilities. This strategy will not only enhance the accessibility of services and reduce travel time and costs for individuals but will also potentially increase the frequency of service usage, thereby improving the overall community health standard.

From the author's on-site investigations, it was found that during weekdays, up to 71% of those registering at community health service facilities were elderly. This data suggests that elderly individuals predominantly use these facilities on weekdays. The map indicates that the population aged 60 and above is mainly concentrated in the red areas (Figure 5). It's recommended to consider adding community health service facilities in these areas. The density distribution of the elderly can also be a basis for phased construction of health facilities. It's advisable to prioritize establishing community health service facilities in areas with a higher concentration of elderly residents in the current phase.

5 Conclusion

This study reveals that although the overall development of primary medical institutions in Beijing is relatively good compared to other domestic regions, there still exists an imbalance in the distribution of community health service facilities in the Dongcheng and Xicheng districts relative to the distribution of the elderly population. Additionally, urban peripheral jurisdictions also have a shortage in facility distribution. Such imbalances can lead to either wastage of resources or service inadequacies, consequently affecting the overall health status of the community.

Through GIS simulation, we conducted an in-depth analysis of the distribution of community health service facilities. The results indicate that some facilities are located too closely to one another, leading to overlapping service areas, which could result in a waste of medical resources. Conversely, certain areas have facilities located too far apart, making it challenging for the elderly, particularly those with mobility issues, to access medical services. Based on these observations, this research has proposed a more balanced optimization layout for grassroots community health service facilities.

During the process of determining service areas for community health service facilities, considering only one tier of medical facility is insufficient. Higher-tier medical facilities functionally substitute lower-tier ones. Secondary hospitals are mostly specialized and do not serve as substitutes. Therefore, the influence of tertiary general hospitals surrounding community health service facilities should be considered, ensuring there is no overlap in their service areas. Moreover, while high-tier medical facilities are equipped with abundant medical resources, their vast size and complex departmental structure pose additional challenges to elderly patients. Over-reliance on high-tier hospitals can also disrupt the normal operation of the referral system, further burdening the healthcare system. Hence, further research and

optimization of collaborative work models across different tiers of medical institutions are essential.

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