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ORIGINAL RESEARCH

Analysis and Optimization of Automated External Defibrillator (AED) Configuration in Chinese Cities: A Case Study of Dongcheng District, Beijing

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Purpose: To explore strategies for optimizing Automated External Defibrillator (AED) configuration in urban areas of China and improving the treatment conditions for out-of-hospital cardiac arrest (OHCA) patients.

Material and Methods: Taking Dongcheng District, Beijing as the research object, spatial data such as administrative divisions, transportation road networks, AED configuration points, and points of interest in key public places, as well as non-spatial data such as population statistics, were collected. Service area analysis and location-allocation models were used to analyze the current status of AED configuration and explore optimization strategies for AED deployment.

Results: As of September 2024, a total of 86 AEDs had been configured in Dongcheng District, and their service area covered 13.74% of the district. The combined service area of AEDs and hospitals covered 82.62% of the district. After achieving the goal of full AED coverage in key public places in the future, AED service area will cover 34.80% of the district, and the combined service area of AEDs and hospitals will cover 85.92% of the district. According to the optimization plan proposed in this study, an additional 218 AEDs are needed in Dongcheng District, bringing the total number of AEDs to 519. At this point, AED service area will cover 50.62% of the district, and the combined service area of AEDs and hospitals will cover 97.28%.

Conclusion: The AED configuration optimization strategy proposed in this study is highly reasonable, and relevant government agencies can refer to this framework to optimize the AED deployment in urban areas. Additionally, technologies such as the Internet of Things and drones can be leveraged to establish urban AED search and delivery platforms, further enhancing the accessibility and utilization rate of AED to achieve optimal treatment outcomes for OHCA patients and save more lives.

Keywords: AED, ArcGIS, configuration optimization, service area analysis, location-allocation model

Introduction

Cardiovascular disease (CVD) is the primary health threat in China. It is estimated that there are currently 330 million CVD patients in China, and the prevalence rate remains in a continuous upward trend.[1] In 2021, CVD accounted for 48.98% and 47.35% of total deaths in rural and urban areas respectively.[2] Cardiac arrest (CA) is significantly concerning due to its high mortality and disability rates. The overall incidence of CA in China is 97.1 per 100,000 people, with over 90% occurring outside hospitals. The survival rate from out-of-hospital cardiac arrest (OHCA) is less than 1%, far lower than the 10–15% rate in developed countries.[3]

The "golden rescue window" for CA patients is within 4 minutes.[4] For every minute of delay in treatment, the survival rate decreases by 7%-10%.[5] Studies indicate that survival rates can reach 50–70% if cardiopulmonary resuscitation (CPR) is initiated within 1 minute and defibrillation is provided within 3–5 minutes.[6] Automated External Defibrillator (AED), a portable medical devices, can diagnose specific arrhythmias and deliver electric shocks. AED is designed for use by non-professionals to rescue CA patients. When OHCA occurs, ambulances may not arrive within the golden 4-minute window, making bystander intervention crucial.

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However, only 17.0% of the Chinese public performs CPR, and the AED utilization rate is less than 0.1%—key factors contributing to the low survival rate.[3] Improving AED accessibility is therefore vital for improving OHCA outcomes. However, due to China's large population, vast territory, and the relatively late deployment of AED, problems still exist in the current AED deployment, such as insufficient quantity, uneven distribution, and incomplete coverage. According to the data released by the government and authoritative media, as of 2024, the Red Cross system in China has cumulatively equipped more than 83,000 AEDs in public places across the country. Beijing has equipped nearly 7000 AEDs, with an average of 32 AEDs per 100,000 people. Shanghai has equipped more than 5100 AEDs, with an average of 20 AEDs per 100,000 people. This is far from the standard level of 100 AEDs per 100,000 people proposed by the American Heart Association. This problem is more prominent in less developed cities and vast rural areas.

The *Healthy China Initiative (2019–2030)* states that

> Standards for equipping public spaces with emergency rescue facilities and equipment should be improved. First-aid medications, equipment, and facilities, including AED, should be installed in densely populated areas such as schools, government agencies, enterprises, airports, train stations, ports, shopping malls, and cinemas.

While meeting the numerical requirements for AED deployment is a primary step, optimizing the scientific and rational distribution of AED to ensure balanced coverage across different regions is a more pressing research question. However, academic research on AED configuration in China remains limited.[7] Current deployment strategies, primarily driven by government agencies, largely rely on the general guidelines and regional overviews rather than micro-level analysis of coverage effectiveness and cost-benefit ratios.[8,9]

Beijing, the capital of China and its second-largest city, is dedicated to developing its core functions as a national political center, cultural center, international exchange center, and technological innovation center. During the development and construction of these core functions, Beijing inevitably experiences population growth, talent aggregation, and industrial development, which place higher demands on the configuration level of AED. Meanwhile, conducting research on AED configuration using Beijing as an example can provide guidance and reference for other regions. Therefore, taking Dongcheng District of Beijing as the research object, this study firstly analyzed the current status of AED configuration in the area using geographic analysis methods in the ArcGIS platform. Subsequently, explored an AED configuration optimization scheme that meets practical needs and policy guidance, and analyzed the coverage effect after optimization. We aimed to provide a theoretical basis for AED configuration in Beijing and further offer empirical references for AED configuration in other urban areas of China.

Materials and Methods

Study Area

Dongcheng District, located in the central-eastern part of Beijing, is one of the core functional areas of the capital. The total area of the district is 41.84 km², mainly composed of plain areas. This district is dominated by low-rise buildings, with a dense population and a well-developed road network. As of the end of 2023, Dongcheng District has 17 subdistricts with a permanent population of 703000, including 207000 people aged 60 and above, accounting for 29.45%, and 145000 people aged 65 and above, accounting for 20.63%. Due to the fact that Dongcheng District is mainly composed of commercial and residential areas, and there are multiple tourist attractions in the area, the population is higher during the day than at night. In 2023, Dongcheng District's gross domestic product (GDP) reached CNY 357.43 billion, accounting for 8.17% of Beijing's total GDP.[10]

The emergency medical services (EMS) in Dongcheng District are managed by the Beijing Emergency Center. Beijing Emergency Center is a medical rescue institution directly under the Beijing Municipal Health Commission, which coordinates all medical institutions in the city to jointly undertake tasks such as 120 command and dispatch, daily medical emergency services, emergency medical rescue in case of emergencies, emergency network construction and management, and first aid knowledge popularization and training. In 2023, Beijing received 905200 emergency calls and dispatched 891100 ambulance services. The satisfaction rate of emergency calls reached 99.99%, and the average emergency response time was about 12 minutes.[11]

Data

The population data of Dongcheng District was sourced from the Dongcheng District Bureau of Statistics, obtained through the Seventh National Population Census. Figure 1 illustrates the population density of each subdistrict in Dongcheng District. The current AED configuration points were identified through the WeChat mini-program "Red Cross Emergency Rescue" (which can display the real-time location of all AEDs configured by government agencies in Beijing). Then we obtained the precise coordinates of AEDs through the coordinate picker of Gaode Map. In accordance with the *Three - Year Action Plan for Building Social Emergency Response Capability in Key Public Places in Beijing (2021–2023)*, points of interest including airports, train stations, urban rail transit stations, transportation hubs, intercity bus terminals, parks, scenic spots, sports venues, large commercial supermarkets, theaters, schools, and public non-specialized hospitals above Grade II in Dongcheng District were collected through Gaode Maps. The administrative boundaries of Dongcheng District and its internal subdistricts were obtained from the Geospatial Data Cloud constructed by the Chinese Academy of Sciences. Road networks were derived from Open Street Map, with vehicle speeds for various road types specified in accordance with the *Technical Standards for Highway Engineering (JTG B01-2014)*.

Service Area Analysis

This study employs the service area Analysis module in the Network Analyst extension of GIS to evaluate the coverage of AEDs. This method calculates the service coverage of facilities within a specified impedance range based on their actual distribution and real road network data, and has been widely used in the layout research of public facilities such as medical institutions, schools, and fire stations.[12–14]

After an OHCA occurs, rescuers typically need approximately 1 minute to recognize the emergency and call for help (summoning others and dialing emergency services). Given that the golden rescue window for CA is 4 minutes, rescuers ideally have only 3 minutes to retrieve an AED and return to the scene. This means that the effective coverage radius (impedance) of an AED is approximately 1.5-minute running distance. The study also considers the scenario of hospitals dispatching ambulances for CA patients. Ideally, an ambulance must arrive at the scene within 3 minutes of receiving an emergency call, defining the effective coverage radius (impedance) in this case as approximately 3 minutes of driving distance. Figure 2 visually illustrates this concept.

Location-Allocation Model

The location-allocation model is effective for determining the optimal sites for central facilities to expand service coverage and reduce transportation costs, making it widely used in optimizing the layout of public facilities.[15–17] ArcGIS provides seven types of location-allocation models, including Minimize Impedance, Maximize Coverage, Maximize Capacitated Coverage, Minimize Number of Facilities, Maximize Demand, Maximize Market Share, and Target Market Share. Among them, the Minimize Number of Facilities model aims to cover the maximum number of demand points with the fewest new or adjusted facilities, balancing coverage efficiency and economic benefits. This model is frequently applied to optimize the siting of emergency response services such as fire stations, ambulances, and hospitals.[18–20] Therefore, this study uses the Minimize Number of Facilities model to optimize the spatial distribution of AEDs in Dongcheng District.

Results

Analysis of Current AED Configuration in Dongcheng District

Figure 3 shows the AED configuration in Dongcheng District, Beijing, as of September 2024. By this time, a total of 86 AEDs had been deployed in the district. In terms of the configuration density, *the Three-Year Action Plan for Building Social Emergency Response Capability in Key Public Places in Beijing (2021–2023)* specified a standard of no fewer than 20 AEDs per 100,000 permanent residents. With a permanent population of 701,000 in Dongcheng District by the end of 2024, the average number of AEDs per 100,000 people was 12.27, falling short of the required standard. Using a 1.5-minute running distance as the impedance, the service area of AEDs was calculated, as shown in Figure 4. In terms of coverage, the AED service area covered 5.75 km², accounting for 13.74% of Dongcheng District's total area. This means that only in these 13.74% of areas could OHCA patients access nearby AED within the golden 4-minute window.

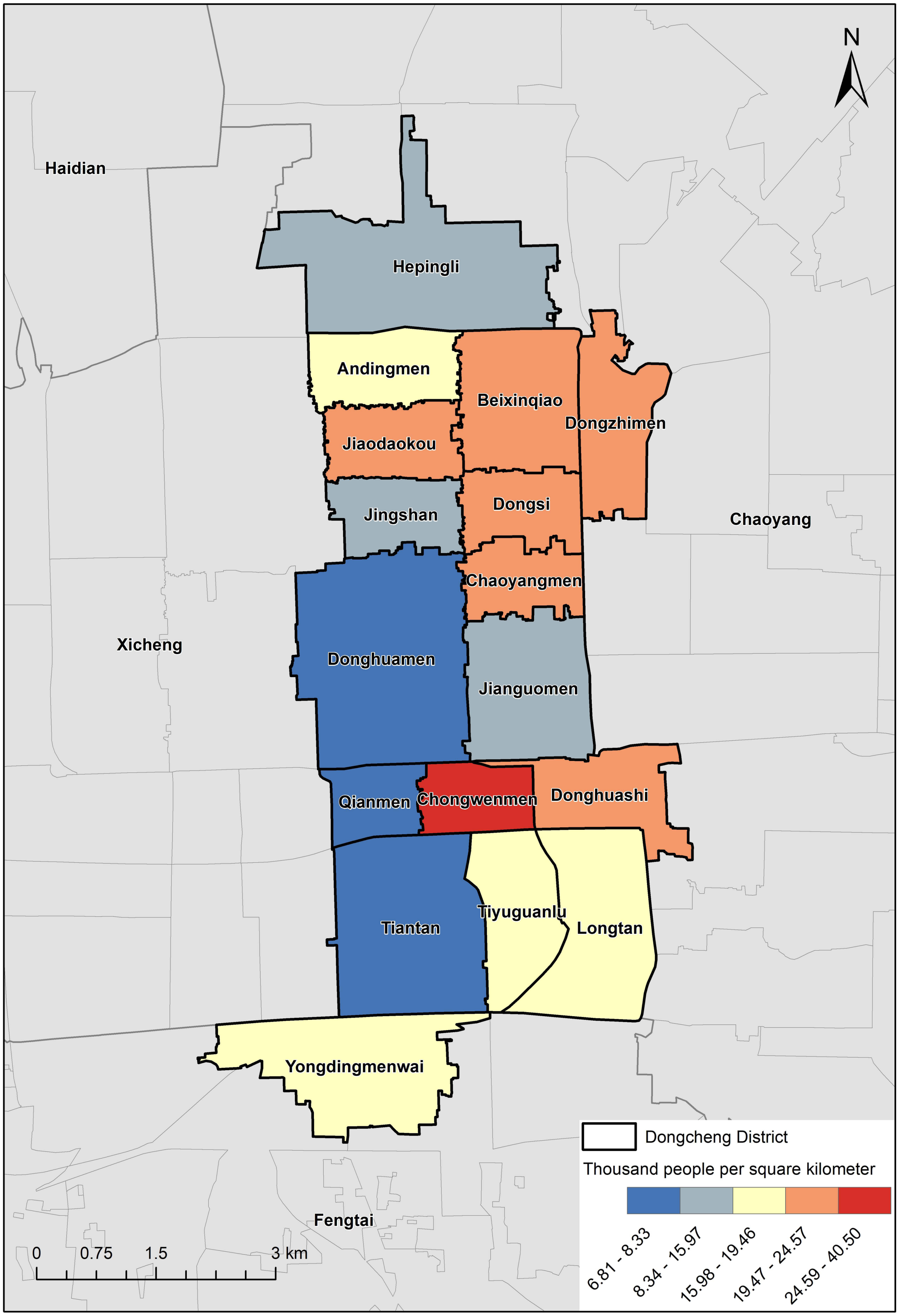

Figure 1 Population Density Map of Dongcheng District.

Another scenario for effective treatment of CA patients is when ambulances dispatched by hospitals arrive at the scene within 3 minutes. Therefore, taking secondary and above public non-specialized hospitals (ensuring the capability to treat CA patients) in Dongcheng District and surrounding areas as facility points, and using a 3-minute driving

Figure 2 Schematic Diagram of Impedance in AED Service Area Analysis.

distance as the impedance, the service area of these hospitals were calculated, as shown in Figure 5. In this case, the service area of these hospitals covered 33.81 km², accounting for 80.81% of the district. Considering both scenarios together, the combined service area of AEDs and hospitals covered 34.57 km², accounting for 82.62% of Dongcheng District's total area. This implies that in the remaining 17.38% of the area, CA patients are highly likely to fail to receive effective treatment once an event occurs.

Future Trends and Analysis of AED Configuration in Dongcheng District

In accordance with the *Three-Year Action Plan for Building Social Emergency Response Capability in Key Public Places in Beijing (2021–2023)* and the *Implementation Plan for Equipping Key Public Places in Beijing with AEDs and Other Emergency Facilities*, Beijing aims to achieve full coverage of AEDs and other emergency equipment in key public spaces across the city, including airports, train stations, urban rail transit stations, transportation hubs, intercity bus terminals, parks, scenic spots, sports venues, large commercial supermarkets, theaters, and schools. Once this goal is achieved, the AED configuration in Dongcheng District will be as shown in Figure 6, and the average number of AEDs per 100,000 people will reach 42.82, far exceeding Beijing's target of at least 20 AEDs per 100,000 permanent residents. The combined service area of AEDs and hospitals at this stage are illustrated in Figure 7. AED service area will cover 14.56 km², accounting for 34.80% of Dongcheng District's total area—a significant increase from 13.74% in September 2024. The integrated service area of AEDs and hospitals will cover 35.95 km², representing 85.92% of the district's total area. Uncovered regions are primarily located in the northwestern, northeastern, and southern parts of Dongcheng District, mainly due to two main reasons. First, these areas have relatively less AED configurations. Also, these regions are predominantly parks, scenic spots, sports venues, or embassy areas, where road networks are underdeveloped or spaces are relatively enclosed. Nonetheless, these areas remain key focuses for optimizing future AED configuration.

Optimization Strategies and Effect Analysis of AED Configuration in Dongcheng District

The goal of AED configuration is to maximize service area coverage across the region. To achieve this, dense grid points were established in areas not covered by existing AED or hospital service area as demand points in the location-allocation model. Rectangular grid points with an interval of 166.67 meters (the AED coverage radius, ie, 1.5-minute running distance) were set up across Dongcheng District as potential facility points. We optimized the AED configuration locations using the Minimize Number of Facilities model in the location-allocation model, and the results are shown in Figure 8. After optimization, 218 new AEDs were added, bringing the total number of AEDs in Dongcheng District to 519—an average of 73.83 units per 100,000 people, approaching the American Heart Association's standard of 100 units per 100,000 people. The combined service area of AEDs and hospitals are illustrated in Figure 9. AED service area now covers 21.18 km², accounting for 50.62% of the district's total area, while the integrated service area of AEDs and hospitals covers 40.70 km², representing 97.28% of the district's total area—essentially achieving full coverage. The remaining uncovered areas are mostly enclosed zones inaccessible to the transportation road networks used in the optimization model, though they may de facto be covered in practice.

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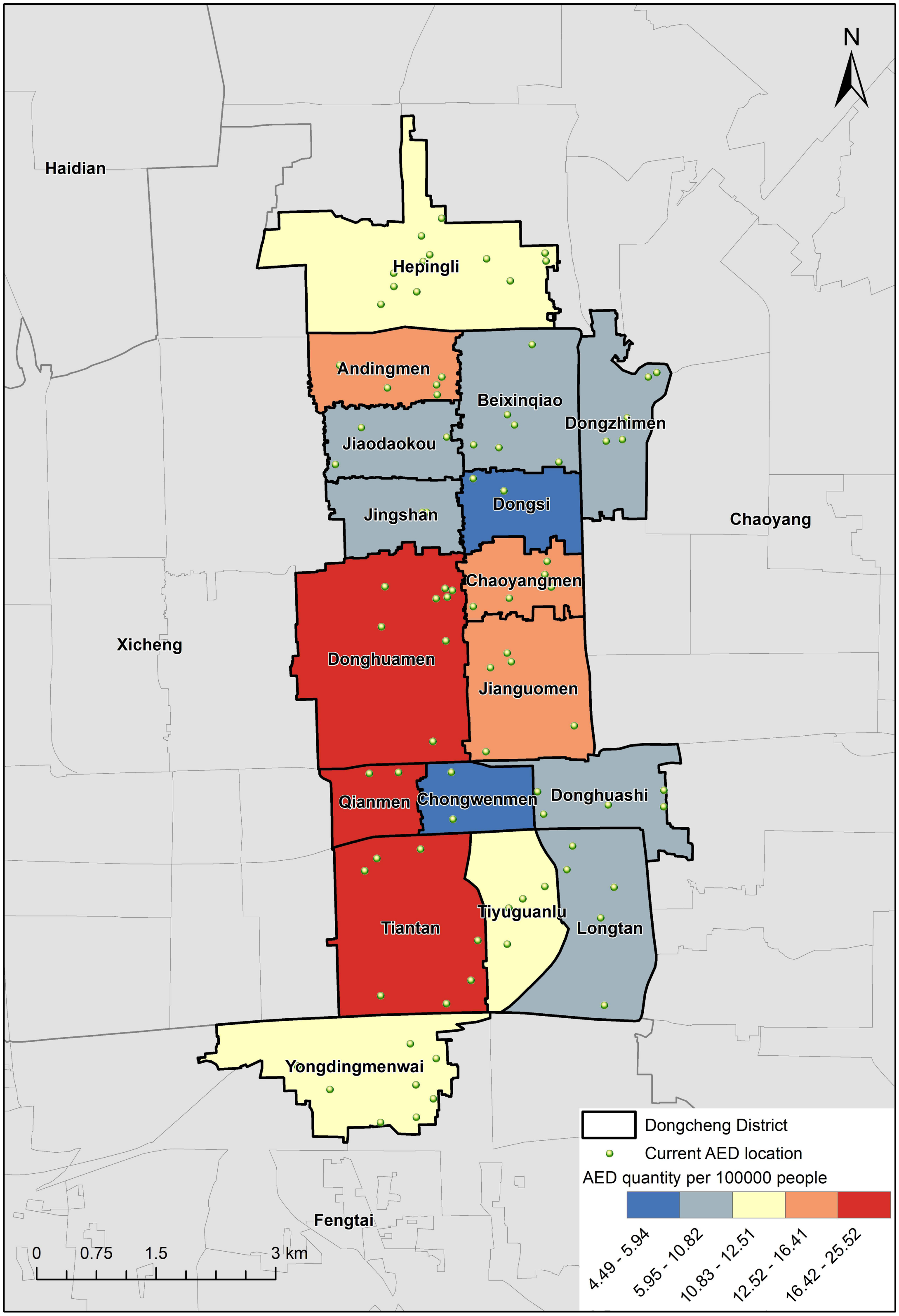

Figure 3 Current AED Configuration Status in Dongcheng District.

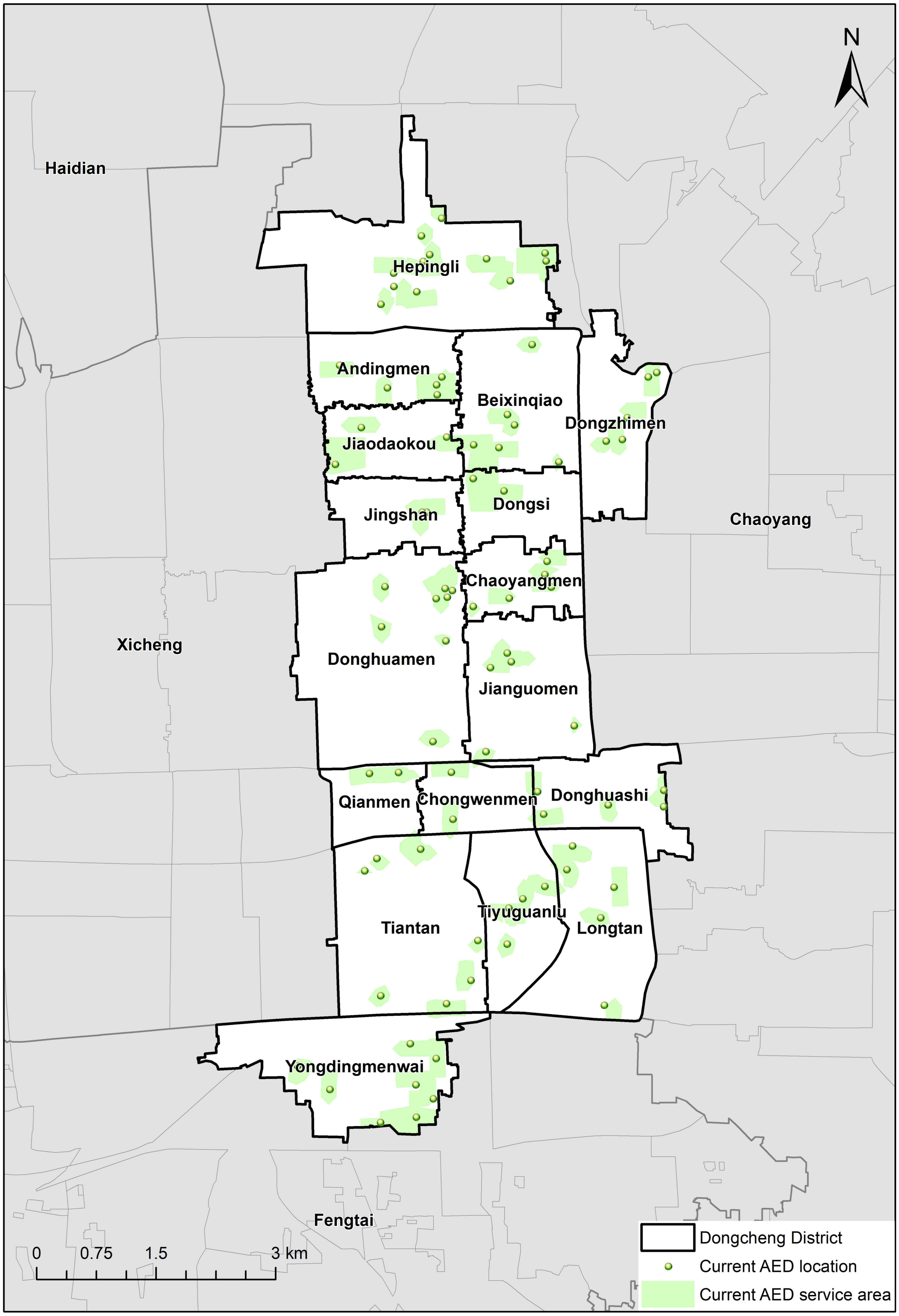

Figure 4 Current AED Service Area in Dongcheng District.

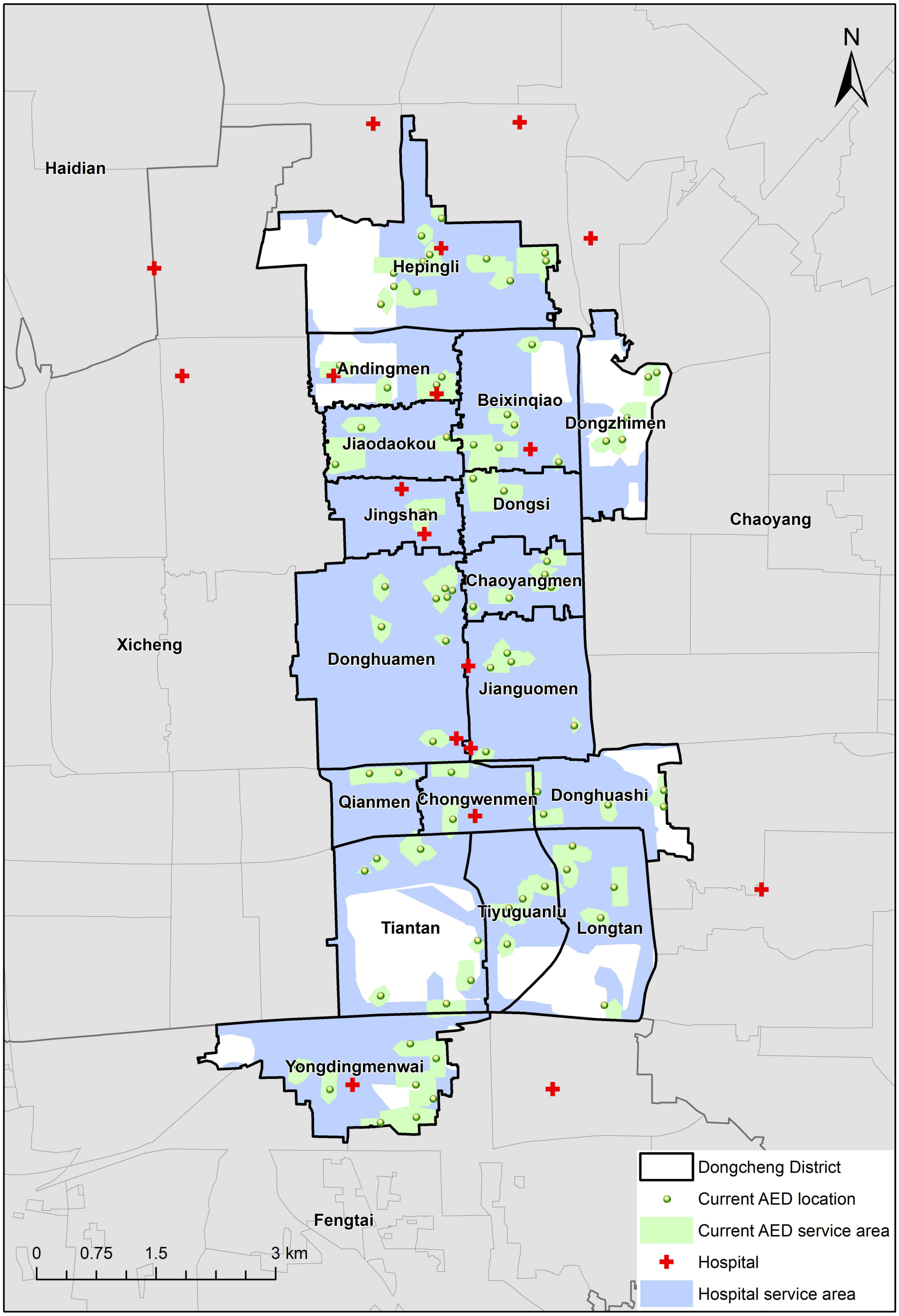

Figure 5 Current AED and Hospital Service Area in Dongcheng District.

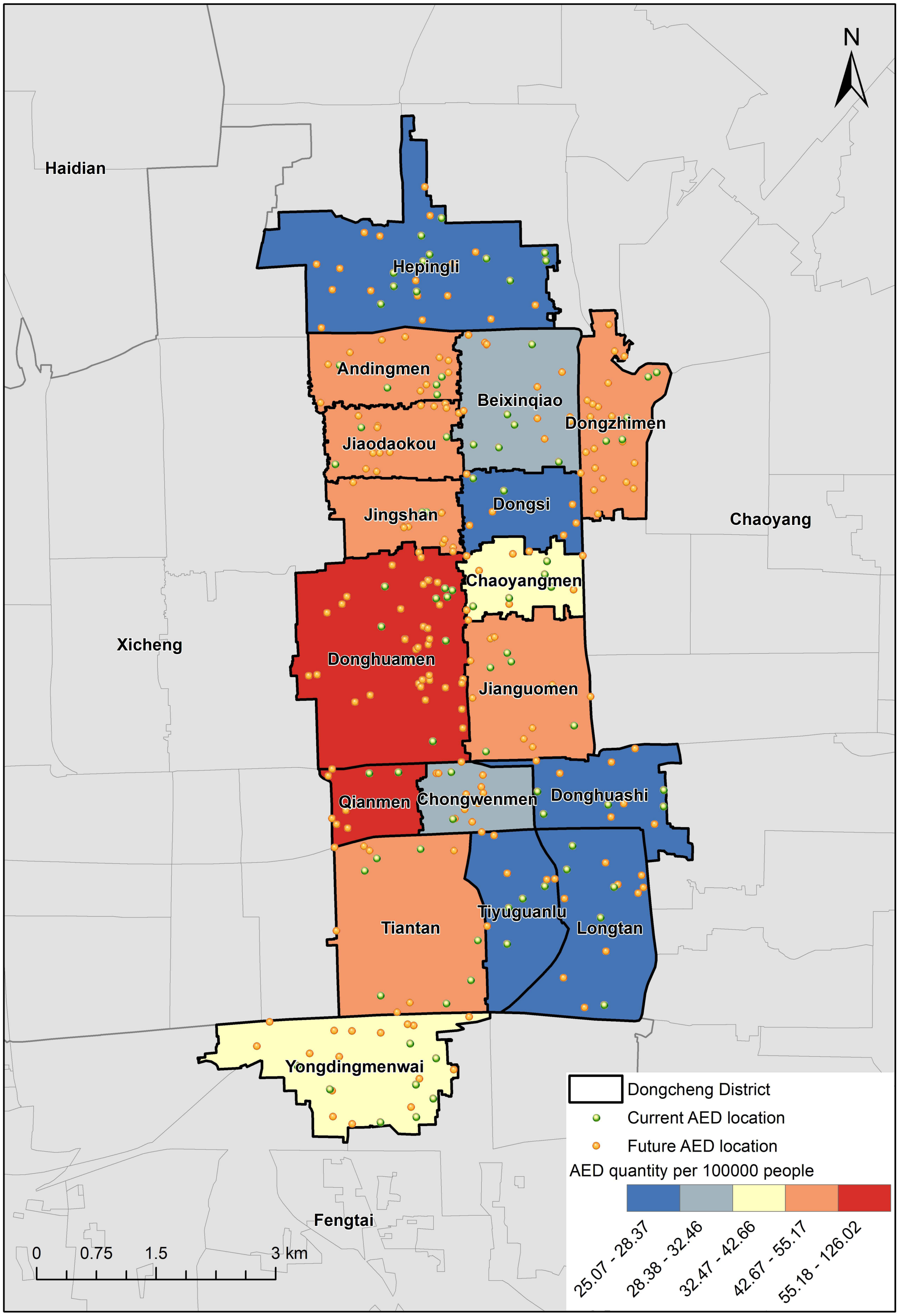

Figure 6 Possible Situations of Future AED Configuration in Dongcheng District.

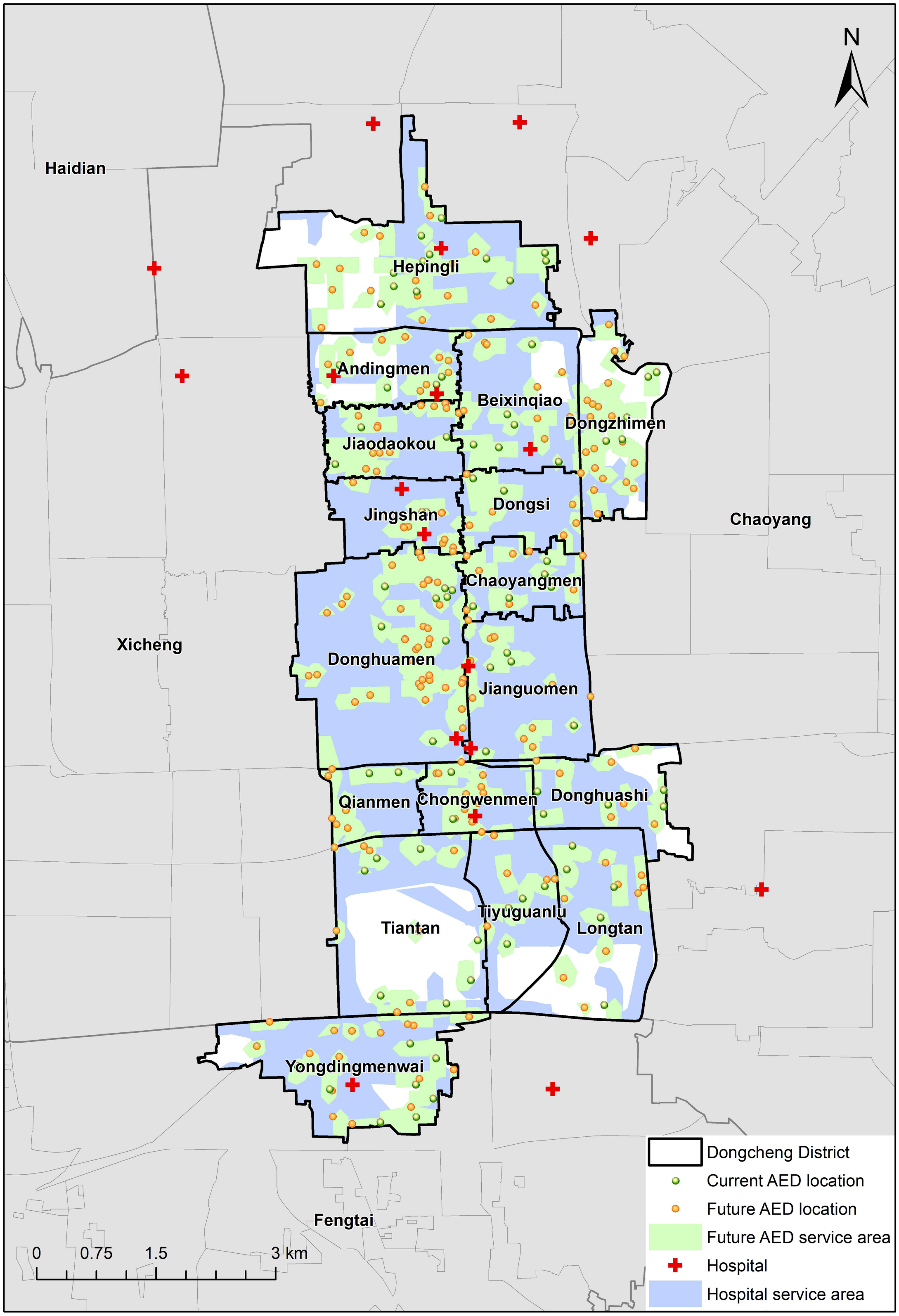

Figure 7 Future AED and Hospital Service Area in Dongcheng District.

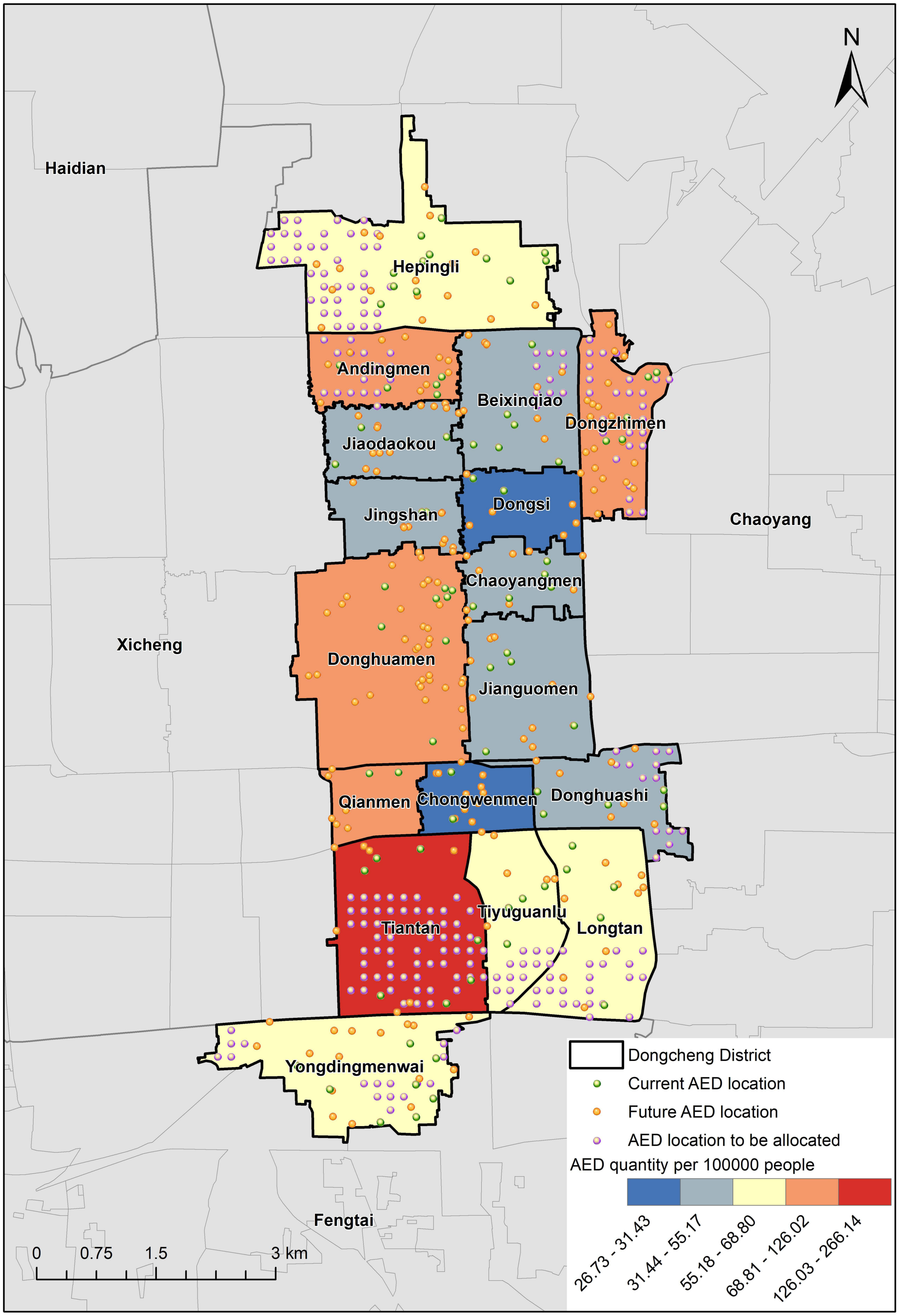

Figure 8 Optimization Plan for AED Configuration in Dongcheng District.

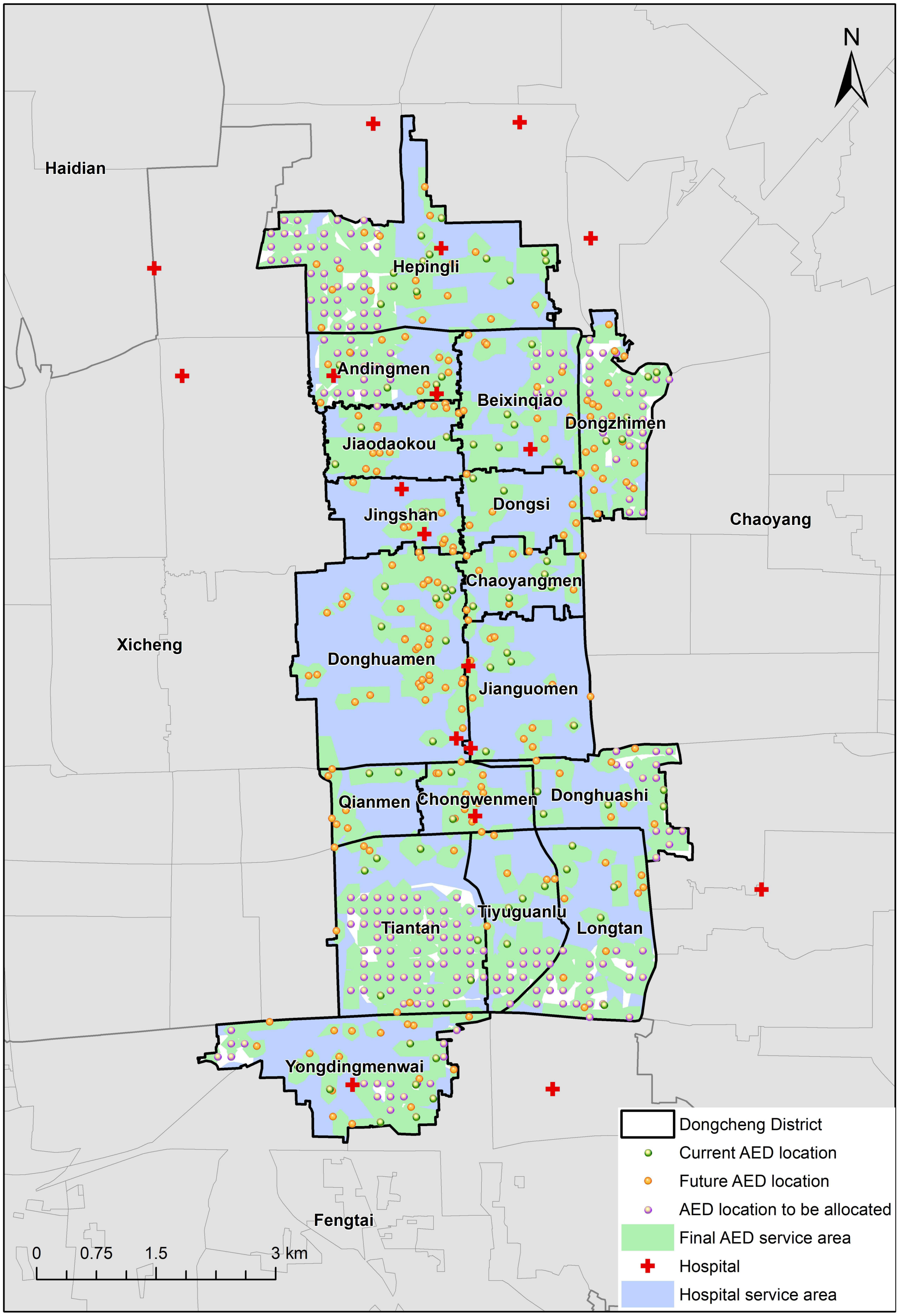

Figure 9 Service Area for AED and Hospital in Dongcheng District after Optimization.

Discussion

Rationality of AED Configuration Optimization Strategies Based on Service Area Analysis and Location-Allocation Model

In this study, taking Dongcheng District, Beijing as an example, we first collected current AED configuration data, analyzed the service coverage, and considered the scenario of hospitals dispatching ambulances for rescue. Subsequently, in accordance with relevant policy requirements, we evaluated the service coverage of AEDs and hospitals after achieving full AED coverage in key public places over the next period, identifying uncovered areas. Finally, using the Minimize Number of Facilities model in the location-allocation model, we explored AED configuration optimization strategies. After optimization, the service area of AEDs and hospitals essentially achieved full coverage of the district. This indicates that the AED configuration optimization strategy proposed in this study has strong rationality and can provide a reference for the AED configuration optimization in urban areas of China.

This study also has several limitations. On the one hand, our analysis was conducted in a two-dimensional plane, whereas in reality, factors such as high-rise buildings and complex architectures may increase the time cost for accessing an AED. On the other hand, although the optimization scheme in this study fundamentally achieved full coverage, there may be situations where a single AED is insufficient in areas with extremely dense populations. Therefore, when applying the findings to more micro-specific scenarios, managers need to comprehensively consider these complex real-world issues and further increase the number of AED configurations.

Optimizing AED Management and Delivery Methods to Further Enhance AED Accessibility and Utilization

Our study found that in the AED optimization scheme, the configuration density of AEDs in parks, scenic spots, and other venues is excessively high. This is because the underdeveloped road networks in these areas reduce the service coverage of individual AEDs. For example, in Tiantan Park, covering approximately 2.73 km^2, more than 50 AEDs are deployed, far exceeding actual demand and causing serious waste of AED resources. In reality, the management departments of these venues can optimize AED deployment and allocation to meet real-world needs with fewer devices, thereby further improving AED accessibility and utilization. Scholars have proposed and explored solutions for AED delivery via emergency drones, which offers a promising approach to address this issue.[21–24] Furthermore, government emergency management departments should integrate new technologies such as the Internet of Things and drones to establish urban AED locators and delivery platforms as soon as possible. In the event of an OHCA, rescuers can use the platform to locate the nearest AED and request timely delivery. The platform would then dispatch AED to the scene via drones, overcoming limitations posed by congested and complex road networks and offering more precious time for treating OHCA patients.

Further Enhancing Public Willingness and Competence in Emergency Response

For the treatment of OHCA patients, optimizing AED configuration only addresses the issue of emergency equipment. A deeper challenge lies in whether bystanders are willing and capable to provide rescue. *The China Cardiac Arrest and Cardiopulmonary Resuscitation Report (2022 Edition)* shows that in recent years, the proportion of the Chinese public performing CPR was only 17.0%, and the proportion of AED use was less than 0.1%.[3] This problem stems from two main factors. On the one hand, some people may dare not provide rescue due to concerns about assuming responsibility for failed treatment. On the other hand, a considerable portion of the public has not received relevant emergency rescue training and is unfamiliar with the use of AEDs. For the first issue, to eliminate rescuers' concerns, Article 184 of the *General Provisions of the Civil Law of the People's Republic of China* (commonly known as the "Good Samaritan Law"), which came into effect on October 1, 2017, clearly stipulates that rescuers shall not bear civil liability for harm caused to the assisted person during voluntary emergency rescue actions. However, current awareness of this law remains low. It is recommended to strengthen its popularization to enhance the public's willingness to provide rescue. For the second issue, government agencies need to pay key attention to increase investment and integrate forces from the Red Cross Society, hospitals, communities, schools, and enterprises. Efforts should be continuously intensified to strengthen emergency rescue training for key populations, expand the coverage of emergency rescue training, and enhance the public's emergency rescue capabilities.

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Conclusion

Based on the ArcGIS platform, this study comprehensively considered two real-world scenarios: rescuers running to retrieve an AED and hospitals dispatching ambulances for rescue. By applying service area analysis and a location allocation model, we determined the optimal configuration points for newly added AEDs, which can achieve full coverage of AED and hospital service area within the district with fewer AEDs and satisfy the rescue needs of OHCA patients while balancing the cost-effectiveness of AED deployment. In the long term, we recommend that the government promptly establish an urban AED locator and delivery platform to further enhance AED accessibility and utilization. Meanwhile, efforts should be intensified to publicize the "Good Samaritan Law" and strengthen emergency response training to boost public willingness and competence in providing first aid. These measures will help achieve optimal treatment outcomes for OHCA patients and save more lives.

Abbreviations

AED, automated external defibrillator; CA, cardiac arrest; OHCA, out-of-hospital cardiac arrest; CVD, cardiovascular disease; CPR, cardiopulmonary resuscitation; GDP, gross domestic product.

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Disclosure

The authors report no conflicts of interest in this work.

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