International Journal of *Geo-Information*

MDPI

Article

Observed Equity and Driving Factors of Automated External Defibrillators: A Case Study Using WeChat Applet Data

Shunyi Liao [1,2,3], Feng Gao [1,2,3,*], Lei Feng [1,2,3], Jiemin Wu [1,2,3], Zexia Wang [1,2,3] and Wangyang Chen [1,2,3]

1 Guangzhou Urban Planning & Design Survey Research Institute, Guangzhou 510060, China; liaoshunyi@gzpi.com.cn (S.L.); fenglei@gzpi.com.cn (L.F.); wujiemin@gzpi.com.cn (J.W.); wangzexia@gzpi.com.cn (Z.W.); e0403826@u.nus.edu (W.C.)
2 Collaborative Innovation Center for Natural Resources Planning and Marine Technology of Guangzhou, Guangzhou 510060, China
3 Guangdong Enterprise Key Laboratory for Urban Sensing, Monitoring and Early Warning, Guangzhou 510060, China
* Correspondence: 2111801048@e.gzhu.edu.cn

Abstract: Out-of-hospital cardiac arrest (OHCA) causes a high mortality rate each year, which is a threat to human well-being and health. An automated external defibrillator (AED) is an effective device for heart attack-related diseases and is a panacea to save OHCA. Most relevant literature focuses on the spatial distribution, accessibility, and configuration optimization of AED devices, which all belong to the characteristics of the spatial distribution of AED devices. Still, there is a lack of discussion on related potential influencing factors. In addition, analysis of AED facilities involving multiple city comparisons is less considered. In this study, data on AED facilities in two major cities in China were obtained through the WeChat applet. Then, the AED equity at the city and block scales and its socioeconomic factors were analyzed using the Gini coefficient, Lorenz curve, and optimal parameters-based geo-graphical detector (OPGD) model. Results show that the number of AEDs in Shenzhen was about eight-times that of in Guangzhou. The distribution of AEDs in Shenzhen was more equitable with a global Gini of 0.347, higher than that in Guangzhou with a global Gini of 0.504. As for the determinants of AED equity, residential density was the most significant determinant in both Guangzhou and Shenzhen from the perspective of individual effects on AED equity. Differently, due to the aging population in Guangzhou, the proportion of the elderly in blocks was influential to local AED equity. The local economic development level was crucial to local AED equity in Shenzhen. The results of the interaction detector model illustrate that relatively equitable AED distributions were found in the high-density residential areas with a balance of employment and housing, high-aging residential areas, and high-mobility residential areas in Guangzhou. The area with a high level of local economic development, dense population, and large mobility was the area with a relatively equitable distribution of AEDs in Shenzhen. The results of this paper are conducive to understanding the equity of AEDs and its socio-economic determinants, providing scientific reference for the optimization and management of AEDs.

Keywords: AED; equity; WeChat applet; optimal parameters-based geographical detector

check for updates

Citation: Liao, S.; Gao, F.; Feng, L.; Wu, J.; Wang, Z.; Chen, W. Observed Equity and Driving Factors of Automated External Defibrillators: A Case Study Using WeChat Applet Data. *ISPRS Int. J. Geo-Inf.* **2023**, *12*, 444. https://doi.org/10.3390/ijgi12110444

Academic Editors: Wolfgang Kainz, Jiangfeng She, Min Yang and Jun Zhu

Received: 30 August 2023
Revised: 24 October 2023
Accepted: 25 October 2023
Published: 30 October 2023

1. Introduction

Out-of-hospital cardiac arrest (OHCA) is an emergency that occurs suddenly outside of a hospital and results in cardiac arrest [1–4]. Causes of OHCA may include heart disease, coronary heart disease, myocardial infarction, sudden heart failure, and respiratory obstruction [2]. When OHCA occurs, the heart stops pumping blood, resulting in insufficient oxygen supply, which can lead to death if first aid measures such as cardiopulmonary resuscitation (CPR) and electrical defibrillation are not performed promptly [5,6]. This is an emergency situation that requires immediate measures for cardiopulmonary resuscitation and the use of an automated external defibrillator (AED) to resume the heart beating on its own as early as possible [7–10]. The overall incidence of cardiac arrest in China in 2021 was 97.1 per 100,000 [11].

The use of an AED is an emergency measure that can be performed in the event of an OHCA, which can provide timely electrical defibrillation to restore normal heart rhythm [9,10,12–14]. The use of an AED can significantly improve survival, depending on a number of factors, including the timing of the implementation of the AED, the cause of the cardiac arrest, and the patient's underlying condition [6,15–17]. The importance of early, timely use of AEDs to improve survival has been widely recognized [9,18–20]. Studies have shown that the use of an AED within the first few minutes of an OHCA occurrence, as well as in highly populated areas such as arenas, airports, and aboard airplanes, can increase survival rates by more than two times. This suggests that the use of an AED during cardiac arrest is critical for improved survival. However, the popularity and coverage of AED facilities in China is far less than that in European and American countries and is still in the preliminary stage [10]. At present, the number of AEDs for every 100,000 people in China was about 15 in 2021 [11]. However, the number of AEDs per 100,000 people in the United States and Japan was 317 and 235, respectively [11]. The coverage of AEDs in large cities in China's coastal provinces is relatively high, especially Shanghai and Guangdong. It is very necessary to plan and implement AED facilities in a massive country like China [14,18]. Therefore, the research on the coverage and equity of the current AED facilities in China's big cities is conducive to further optimizing the distribution of AED facilities and providing feasible planning technology and scientific reference for backward regions and cities.

Due to its importance to human well-being and health, the study on spatial location of AEDs has become a research hotspot in geography, urban planning, emergency medicine, and other specialties [21–27]. The relevant literature mainly focused on spatial distribution, accessibility, and spatial optimization layout. First, the literature with spatial distribution analysis as the main content mainly used GIS and spatial statistical methods to analyze the spatial distribution characteristics of AEDs to determine whether the distribution of AEDs is uniform and whether the potential cardiac arrest risk area is covered [9,10,19,21,27]. This kind of research can help to reveal the imbalance of the distribution of AEDs in cities and provide a basis for the rational layout and planning of AEDs. Secondly, the literature focusing on accessibility analysis mainly used geographic computation and network analysis to assess the accessibility of AEDs, that is, the time and distance for people to reach the nearest AED at any location in a city [10,14,19,20]. This helps to determine the coverage of AEDs and improve the efficiency of emergency treatment. Furthermore, the literature focusing on spatial optimization layout is based on geospatial models and optimization algorithms to determine the best location of AED stations under given resource constraints in order to maximize coverage and accessibility [7,13–15,21]. This type of research helps planners plan and place AED facilities more efficiently.

However, the current literature focusing on the spatial location of AED facilities still has limitations. The first is data reliability. The AED data that studies have relied on came from different sources, and there may be differences in data quality and accuracy. The lack of uniform data standards and updating mechanisms can also affect the accuracy and comparability of studies. Secondly, in the literature with spatial coverage or accessibility as the main content, the research results paid attention to the characteristics of spatial distribution, but there was a lack of further discussion on social and economic factors. Third, most existing studies took a single city or region as the research area and lack horizontal comparison between cities.

It is necessary to solve these three problems. In terms of data availability, although the government's health care department has comprehensive data on local AEDs, it does not disclose the data for administrative reasons. In other words, the use of regularly updated, reliable, and easily accessible data sources is a prerequisite for conducting relevant research. In terms of equity, most of the current literature focuses on the accessibility and layout planning of existing AED facilities, which mainly evaluates the supply and demand relationship in terms of the number and distribution of AED facilities. These aspects of research are critical for the initial stage of AED facilities from scratch. However, subsequent attention should be paid to whether the coverage of AED facilities is equitable in the city, as well as the spatial distribution of AED equity in each local area (blocks) in the city, and its potential influencing factors. Solving these three limitations is conducive to correctly understanding the effectiveness and fairness of AED facilities in the city and then put forward relevant planning strategies.

WeChat is the largest instant messaging social media APP in China, and the WeChat applet is a lightweight software that is implanted into the WeChat for quick access. A WeChat applet called Urban Lifesaving Map, which is regularly updated and released by the authorities, summarizes data on AED facilities in major cities across the country and provides users with convenience in the form of navigational maps. This is the first open-source access to a nationwide AED facility data source and usage port to date, providing a promising data source for related research by simultaneously obtaining AED data from multiple cities with the same data quality and standards.

In this study, data on AED facilities in two major cities in China were obtained through the WeChat applet. The current situation of AED facilities in Guangzhou and Shenzhen was evaluated through the aspects of quantity, distribution, equity, and its determinants. First, the AED equity at city scale and block scale was evaluated based on the Gini coefficient and Lorenz curve. Secondly, the optimal parameters-based geographical detector (OPGD) model was used to quantify the individual explanatory power and interactive explanatory power of socio-economic determinants on local AED equity. Finally, the differences in the status quo of AED facilities in the two cities were compared, and the suggestions and strategies for planning, optimization, and management of AED facilities were put forward.

2. Data and Methods

2.1. Study Area

This study chose Guangzhou and Shenzhen as study areas (Figure 1), which are the center cities in the Guangdong–Hong Kong–Macao Greater Bay Area [28]. Guangzhou is the capital city of Guangdong Province in China and an important economic, transportation, and cultural center of the country. Guangzhou is in the southern part of the Pearl River Delta, with a total area of 7434.4 square kilometers and a population of about 18.734 million. Located in the southern part of Guangdong Province, bordering Hong Kong, Shenzhen is a modern international city in China. The total area of Shenzhen is about 1996.85 square kilometers, and the population is about 17.662 million. Shenzhen is one of the forefront cities of China's reform and opening and an important center of global technological innovation and electronics industry. Previous studies reported that the average annual number of OHCA cases in Guangzhou and Shenzhen were around 874 and 658, respectively [29,30]. In general, it is necessary to pay attention to the status of AED facilities in such megacities with massive population.

2.2. AED Data

In this study, a Python script was used to obtain the AED data from the WeChat applet named City Lifesaving Map (Figure 2). WeChat applet is an application that runs on the WeChat platform, which has a smaller size, faster loading speed, and better user experience compared to traditional mobile applications. WeChat applets can be used directly in WeChat without downloading and installing, and users can open them by scanning a QR code, searching, or from messages shared by friends. In other words, this WeChat applet solves the problem of multi-city AED data integration and update and provides open-source data information for the public.

Figure 1. Study areas.

Figure 2. The acquisition of AED data.

First, we decomposed Guangzhou and Shenzhen into 500 m grids and obtained the AED facility address information in each grid by traversing the query. Then, the addresses of the AED facilities in Guangzhou and Shenzhen were converted into latitude and longitude coordinates through the geocoding service in Baidu Map API. A total of 6888 AED facilities in Shenzhen and 878 AED facilities in Guangzhou were acquired in the study in December 2022. The difference is less than 5% from the number published on the official website of the National Health and Health Commission, indicating that the data acquisition method in this study is scientific and the data acquisition is suitable for further analysis.

2.3. Methods

2.3.1. Overall Workflow

In general, the research methods were divided into three aspects: data collection, equity assessment, and determinant analysis (Figure 3). First, the data collection part has been described in the Data section. Then, the AEDs of the two cities were visualized in an intuitive way by using the kernel density method in ArcMap. The main methods used in equity evaluation were the GINI coefficient and the Lorenz curve. The equity evaluation was based on a multi-scale: city scale for comparison and block scale for further determinants analysis. Finally, determinant analysis applied the OPGD model to quantify the differences in the influencing factors of AED equity in Guangzhou and Shenzhen, including the individual effect of each factor on equity and the interaction effect of factor pairs on equity.

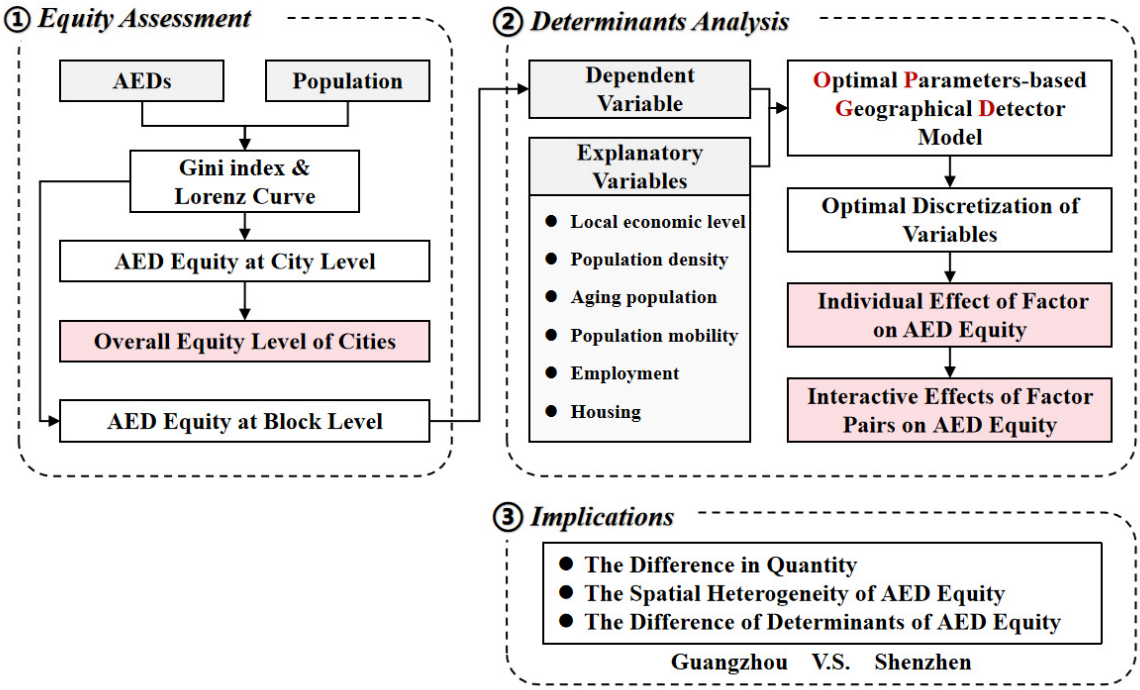

Figure 3. The workflow of the study.

2.3.2. Equity Assessment with Gini Index and Lorenz Curve

Measuring the AED equity at the city and block scale is of great necessity to understand the supply and demand balance between AED configuration and serving the local population. This study used the Gini coefficient and Lorenz curve to quantify AED equity, a combination commonly used to measure a variety of distributional inequalities, including income, wealth, education, and health [31–35]. The Gini coefficient and the Lorenz curve provide an intuitive way to visualize and quantify the extent of inequality, providing policymakers and researchers with tools to assess and compare inequality across different groups or regions [33].

The Gini coefficient is calculated using the Lorenz curve. The Lorenz curve is a chart line used to represent the distribution of cumulative AED relative to the proportion of the population. On this curve, the horizontal axis represents the cumulative population percentage and the vertical axis represents the cumulative AED percentage. First, calculate the Lorenz curve (usually a diagonal line) for equal distribution based on the total population and total AED in the data. Secondly, the area between the Lorenz curve and the completely equal distribution curve is calculated, that is, the area under the Lorenz curve. Finally, the Gini coefficient is equal to the ratio between the area under the Lorenz curve and the area under the perfectly equal distribution curve. The closer the Gini coefficient is to 1, the more unequal the distribution of AED is. The closer it is to 0, the more equal the AED distribution.

Therefore, the Gini coefficient can be expressed as the ratio of the area A to the area A + B (Figure 4):

$$\text{Gini} = \text{A}/(\text{A} + \text{B}) \tag{1}$$

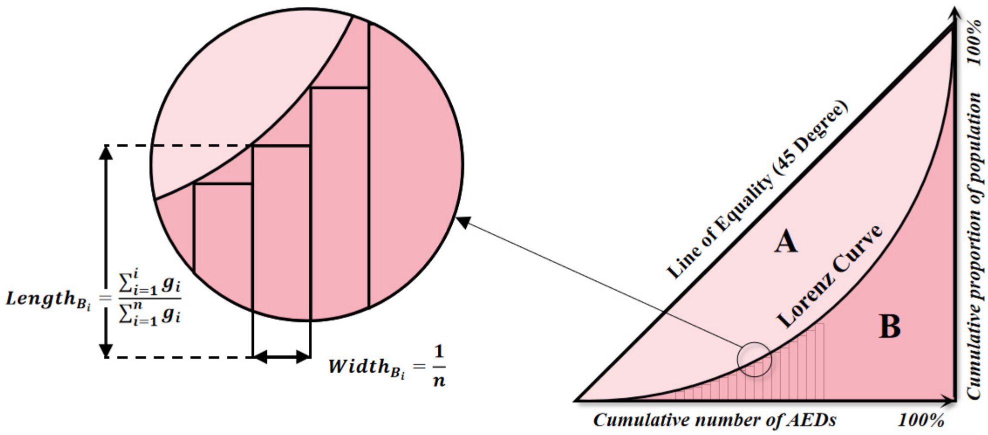

Figure 4. Illustrative diagram of the Gini coefficient and Lorenz curve.

2.3.3. Optimal Parameters-Based Geographical Detector (OPGD) Model

This study used the OPGD model to quantify and compare the influencing factors of AED equity in Guangzhou and Shenzhen. The OPGD model is an optimized version of the geographical detector model [36]. Compared with various types of regression models, the original geographical detector model has the advantage of quantifying the interactive influence between factors on dependent variables [37]. In addition, since the geographical detector model belongs to the nonlinear model, it can avoid multicollinearity in essence. However, the modifiable areal unit problem (MAUP) is a problem faced by the geographical detector model [38]. That is, different combinations of discretization methods and the number of intervals in factor data can affect model results [39]. It is inefficient and time-consuming to solve MAUP when traditional geographical detector model is used for modeling.

The improved version, OPGD model, is developed based on R, with automatic integration of optimal discretization methods and the number of intervals to output optimal model results [36]. Compared with the traditional version, the automatic filter discretization combination and the ability to resolve MAUP are added [40]. Consistent with the traditional version, the OPGD model has four sub-models where factor detectors and interactive detectors were used in this study. The factor detector can be calculated as follows:

$$q = 1 - \frac{\sum_{h=1}^{L} N_h \sigma_h^2}{N_{\sigma^2}} \tag{2}$$

where N refers to the N units of the study, which is stratified into h =1, 2, . . . , L stratum; and stratum h consists of N_h units; σ^2 and σ_h^2 refer to the global variance of the AED equity in the study area and the variance of the AED equity in the sub-areas; the individual effect of each variable can be expressed by the q value, ranging from 0 to 1.

In addition, the interaction detector was adopted to quantify the interactive effects between determinants on AED equity. It can identify if a pair of factors enhance or weaken by comparing their interactive q value and each individual q value of theirs, then classify the interactions into categories as follows:

$$\begin{array}{ll} Nonlinear-enhance: & q(A\cap B) > (q(A)+q(B)) \\ Independent: & q(A\cap B) = (q(A)+q(B)) \\ \text{Bi-enhance}: & Max(q(A),\ q(B)) < q(A\cap B) < (q(A)+q(B)) \\ \text{Uni-enhance/weaken}: & Min(q(A),\ q(B)) < q(A\cap B) < Max(q(A),\ q(B)) \\ Nonlinear-weaken: & q(A\cap B) < Min(q(A),\ q(B)) \end{array} \quad (3)$$

2.4. Potential Determinant Selection

This study further identified and quantified the determinants affecting the spatial distribution of AED equity in Guangzhou and Shenzhen using the OPGD model. Based on the AED-related literature [4,7–10,13] and characteristics of the study area, we selected potential determinants from six aspects (Figure 5): local economic level, population density, proportion of elderly people, mobility, company density, and residential density.

Figure 5. Potential determinants of AED equity.

In terms of variable selection, we choose per capita GDP as a variable, representing the level of local economic development. The placement of AED facilities requires a large amount of government financial funds, but the difference in local funding budgets may directly affect the number and distribution of local AED facilities. Second, company and residential density were selected as variables to represent the two most fundamental functions of the city [39]. Whether it is employment-oriented blocks or residence-oriented blocks, there will be high-density population and mobility with different characteristics. Thirdly, in terms of population, we choose two indicators: population density and population mobility, which represent the static (quantity) and dynamic (mobility) characteristics of the population, respectively. Setting up AEDs not only needs to consider areas with high population density, but also needs to pay attention to public spaces with high mobility. Fourthly, considering the aging population in Guangzhou, we chose the proportion of the elderly as a variable, because the elderly are one of the groups prone to OHCA [3,41]. At this stage, based on the prior understanding of the two cities, we preliminarily assumed that the population density and mobility of the two cities have a positive impact on the equity of AED, as does the density of employment and housing. In addition, the impact of regional economic level and proportion of elderly people on AED equity in the two cities may be different.

In terms of data acquisition, the local economic level was expressed by block scale per capita GDP, which, together with population density and proportion of elderly people, were derived from the latest block statistical data provided by the government in December 2022. The company density and residential density were expressed by calculating the POI density of the company and residential community, which was obtained via Baidu Map API in December 2022. Population mobility is calculated based on cell phone signal data at the base station level, which was provided by the local operators with the largest market share [40,42,43]. The population mobility of a block is equal to the difference between the average maximum and average minimum population of all the base stations in the block (Figure 6). The statistics of the six determinants are listed in Table 1.

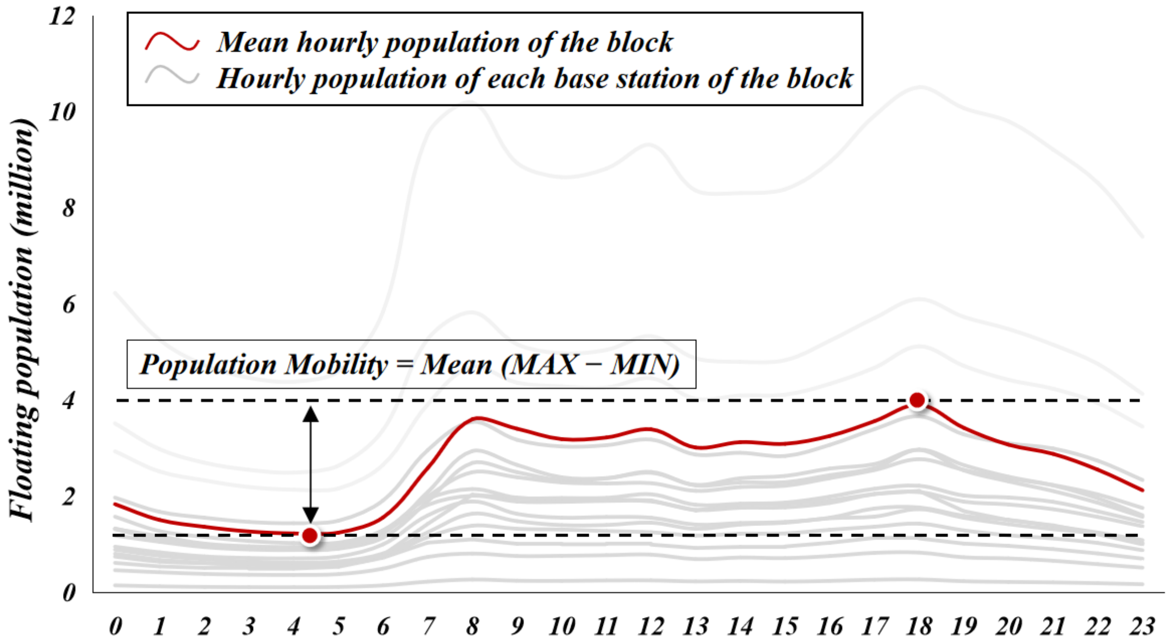

Figure 6. Illustrative diagram of the variable of population mobility based on mobile phone data.

Table 1. Variable statistics.

City	Variable	Abbreviation	Max	Mean	SD
Guangzhou	Local GDP per capita	GDP	115,410	33,197	23,027
	Population density	POP_DEN	18.907	3.623	3.701
	The proportion of the elderly	OLD_RATIO	0.165	0.065	0.037
	Local average mobility	MOBILITY	205.294	102.468	37.117
	Company density	WORK_DEN	784.600	144.867	167.532
	Residential density	LIVE_DEN	111.305	21.063	26.532
Shenzhen	Local GDP per capita	GDP	122,567	35,999	24,401
	Population density	POP_DEN	30.215	3.658	4.551
	The proportion of the elderly	OLD_RATIO	0.047	0.024	0.010
	Local average mobility	MOBILITY	219.023	112.293	35.303
	Company density	WORK_DEN	571.816	121.740	124.890
	Residential density	LIVE_DEN	849.271	14.642	15.852

3. Results and Discussion

3.1. The Number and Distribution of AEDs

Figure 7 shows the spatial distribution of AED facilities in Guangzhou and Shenzhen. We have overlaid the locations of AED points and the density map, and the number of AED facilities in Shenzhen was much higher than that in Guangzhou. In terms of number, the number of AEDs in Shenzhen was about eight-times that in Guangzhou. From the perspective of spatial distribution, AEDs were densely distributed in the downtown area of the two cities. However, the distribution density of AEDs in Shenzhen was generally higher than that in Guangzhou, and the density map of Guangzhou shows that there was still insufficient coverage of AEDs in some areas.

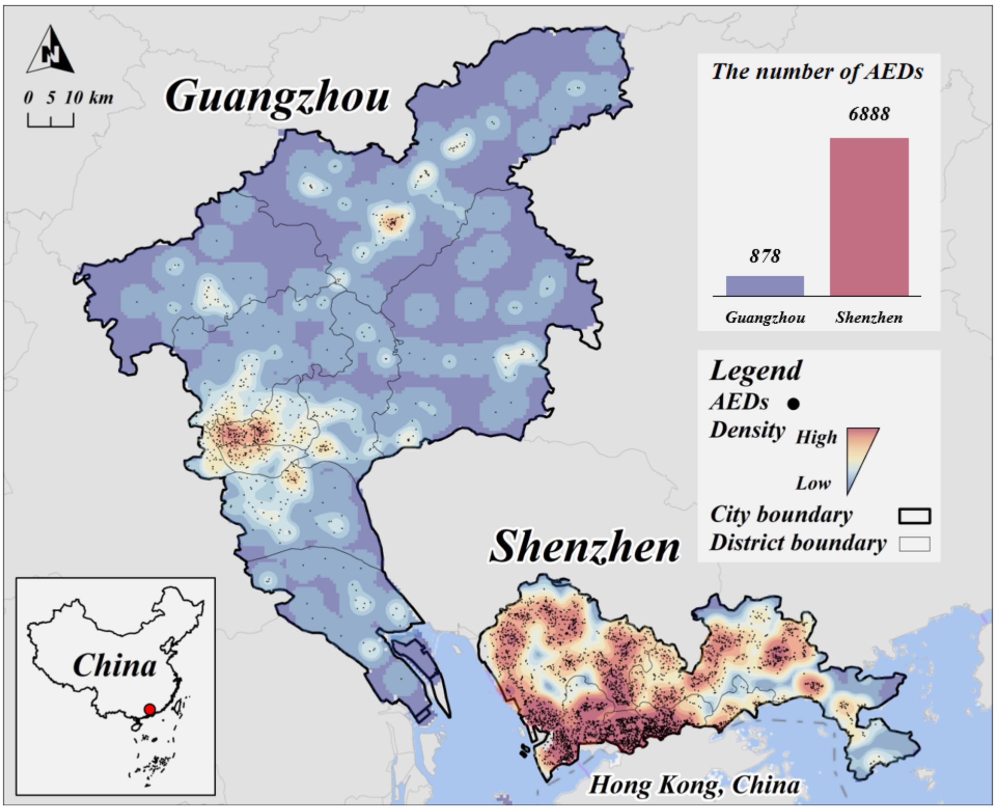

Figure 7. Spatial distribution of AEDs and its density.

3.2. The Equity of AEDs

Figure 8 shows the spatial distribution of block-scale population and number of AEDs in Guangzhou and Shenzhen, as well as the Lorenz curve for the two cities. From the distribution consistency of the number of the population and the number of AEDs, the distribution of the two tended to be more consistent in Shenzhen. Correspondingly, the overall AED distribution in Shenzhen was more equitable with the Gini coefficient of 0.347, while that in Guangzhou was 0.504. The x-axis is the cumulative percentage of the population, and the y-axis is the cumulative percentage of the AEDs. As can be seen in Figure 8, 60% of the city's AEDs served up to 90% of the total population in Guangzhou, while only serving 81% of the total population in Shenzhen. Compared with Guangzhou, the supply and demand relationship of AED facilities in Shenzhen was more balanced.

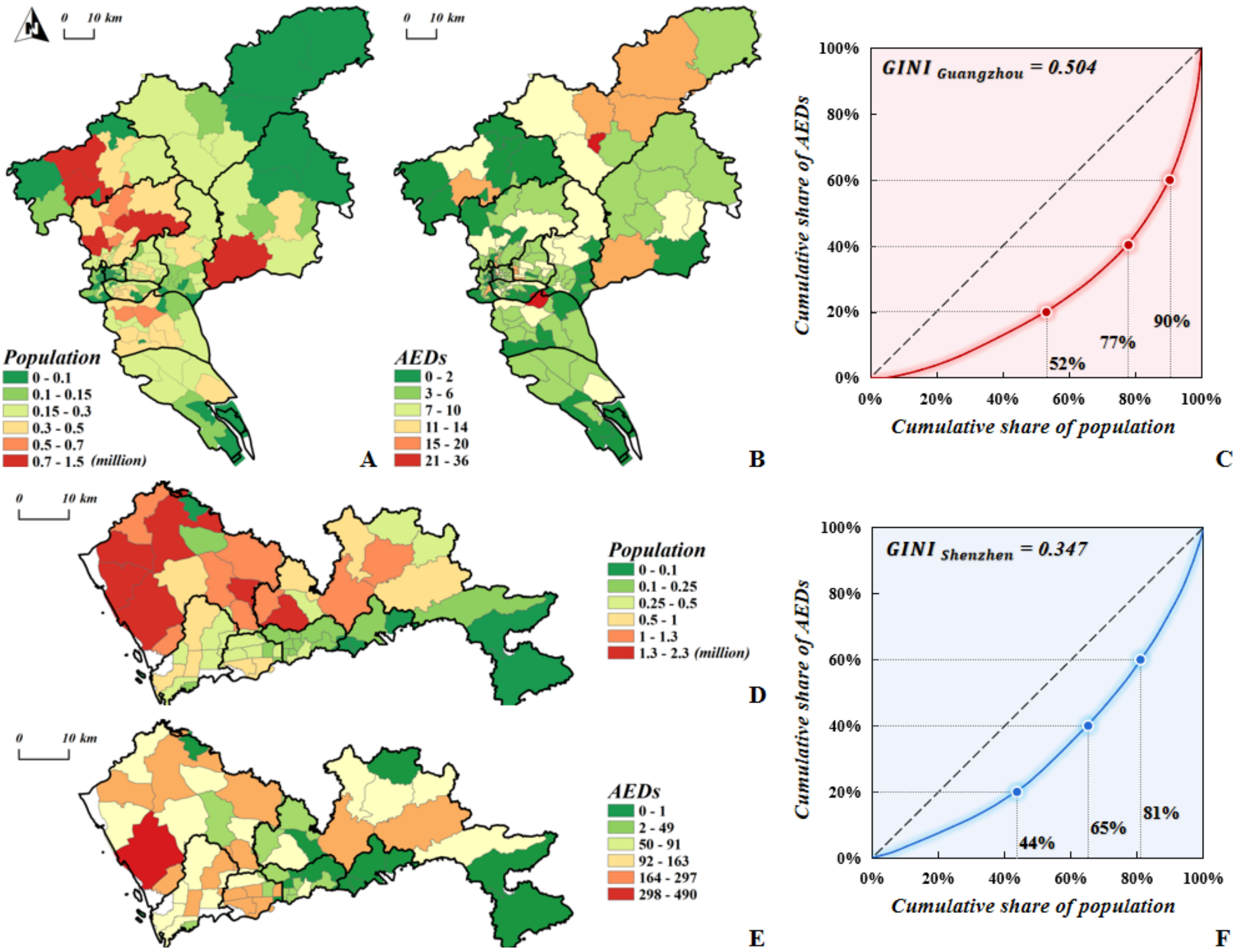

Figure 8. Distribution of population (**A**,**D**) and AEDs (**B**,**E**) and the Gini coefficients (**C**,**F**) at city level.

Figure 9 shows the AED equity at the block level, which is the Gini coefficient calculated based on the population and the AED distribution density. The spatial distribution of block-scale AED equity in Guangzhou shows an obvious single-center structure. The distribution of AEDs in the whole area of Yuexiu District, the west of Tianhe District, the northwest of Haizhu District, the northeast of Liwan District, and the south of Baiyun District of Guangzhou was relatively equitable, while the distribution in the periphery was relatively inequitable. The distribution of AEDs in Futian District, the west of Luohu District, and the south of Nanshan District was more equitable than that in Baoan District in the north of Shenzhen and Yantian District and Longgang District in the east of Shenzhen. The spatial distribution of AED equity in Guangzhou and Shenzhen reflects the difference in the association between the layout and planning of emergency medical facilities and socio-economic factors in the two cities. This calls for a determinant analysis to quantify the influencing factors on AED equity for future planning and management.

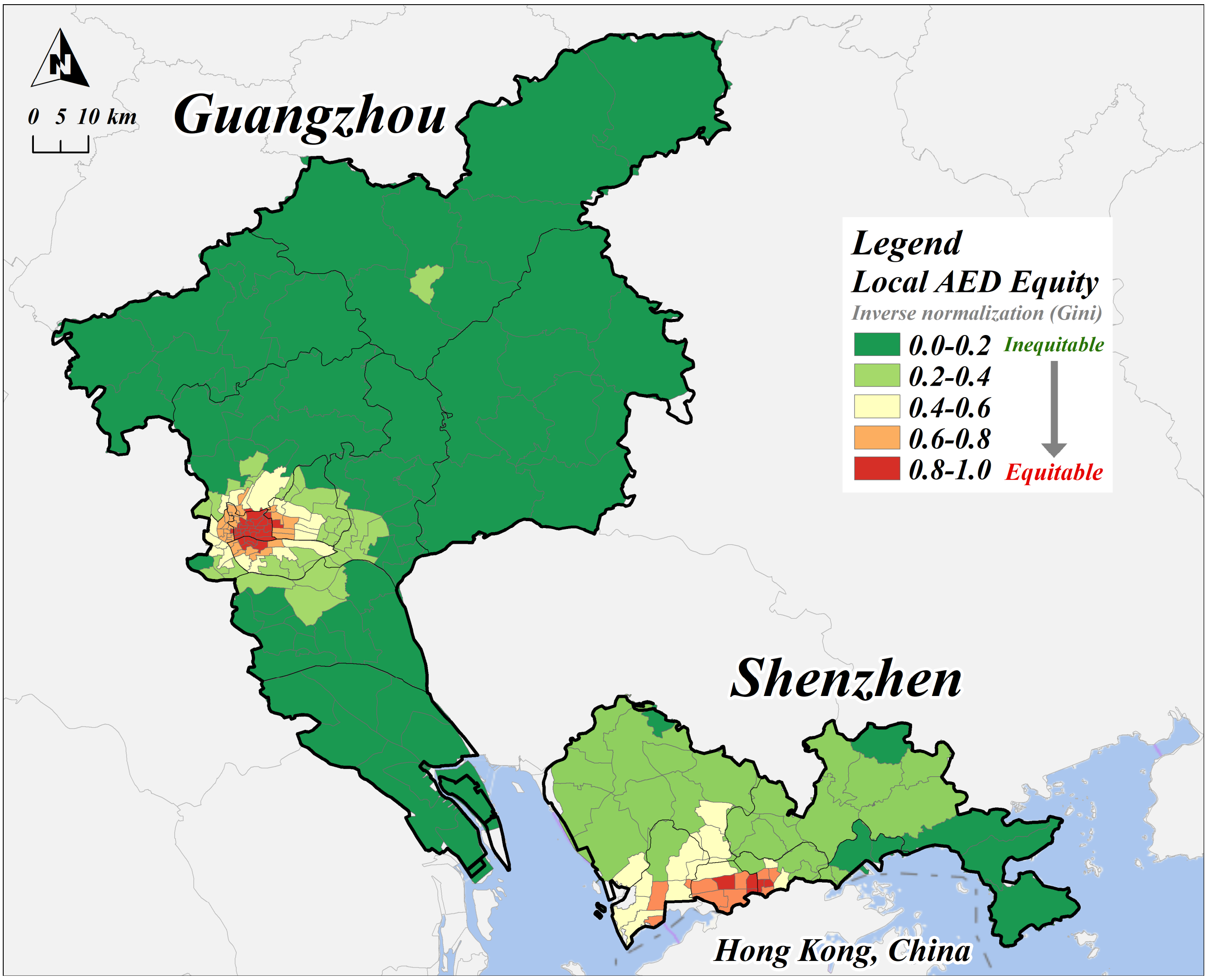

Figure 9. Distribution of the AED equity at block level based on 200 m grid.

3.3. Optimal Discretization of Variables

Figures 10 and 11 present the spatial distribution of the selected potential determinants of AED equity in Guangzhou and Shenzhen. The optimal discretization of variables for addressing the MAUP in modeling are shown in Figures 12 and 13, including the determination of the optimal discretization method and the number of intervals.

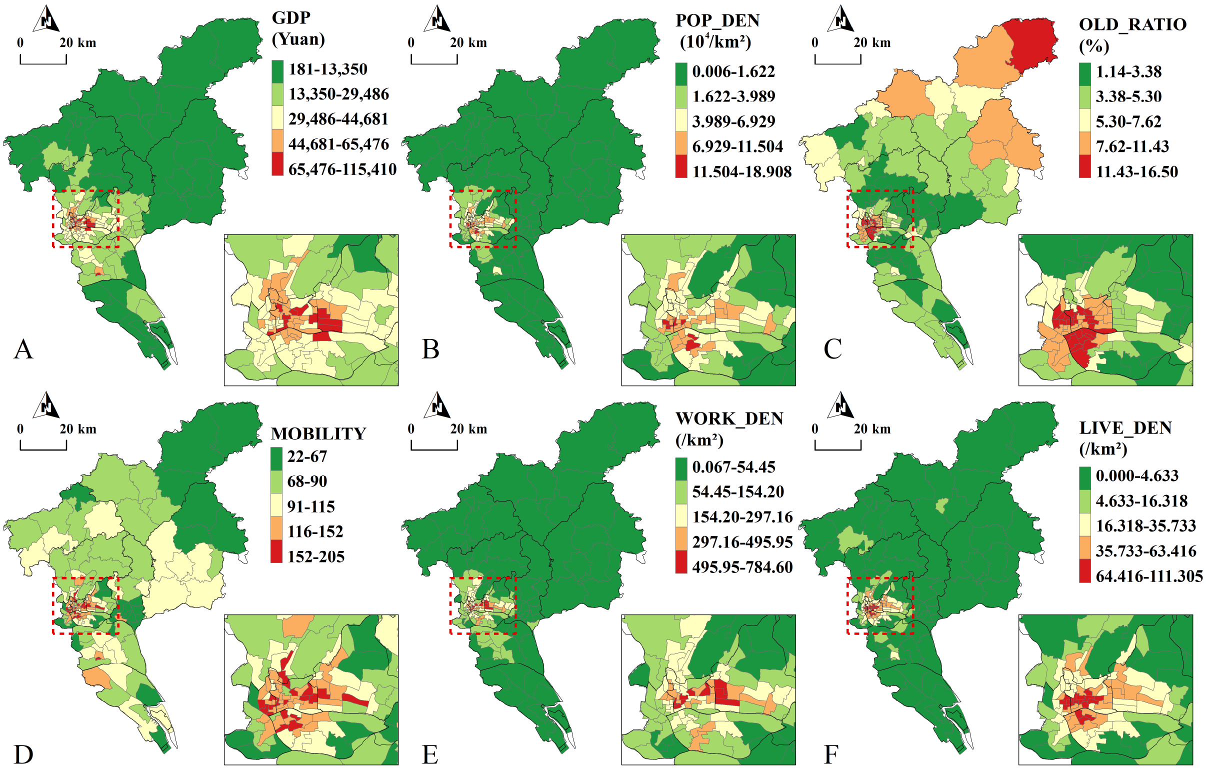

Figure 10. Spatial distribution of determinants in Guangzhou, including GDP (**A**), POP_DEN (**B**), OLD_RATIO (**C**), MOBILITY (**D**), WORK_DEN (**E**), LIVE_DEN (**F**).

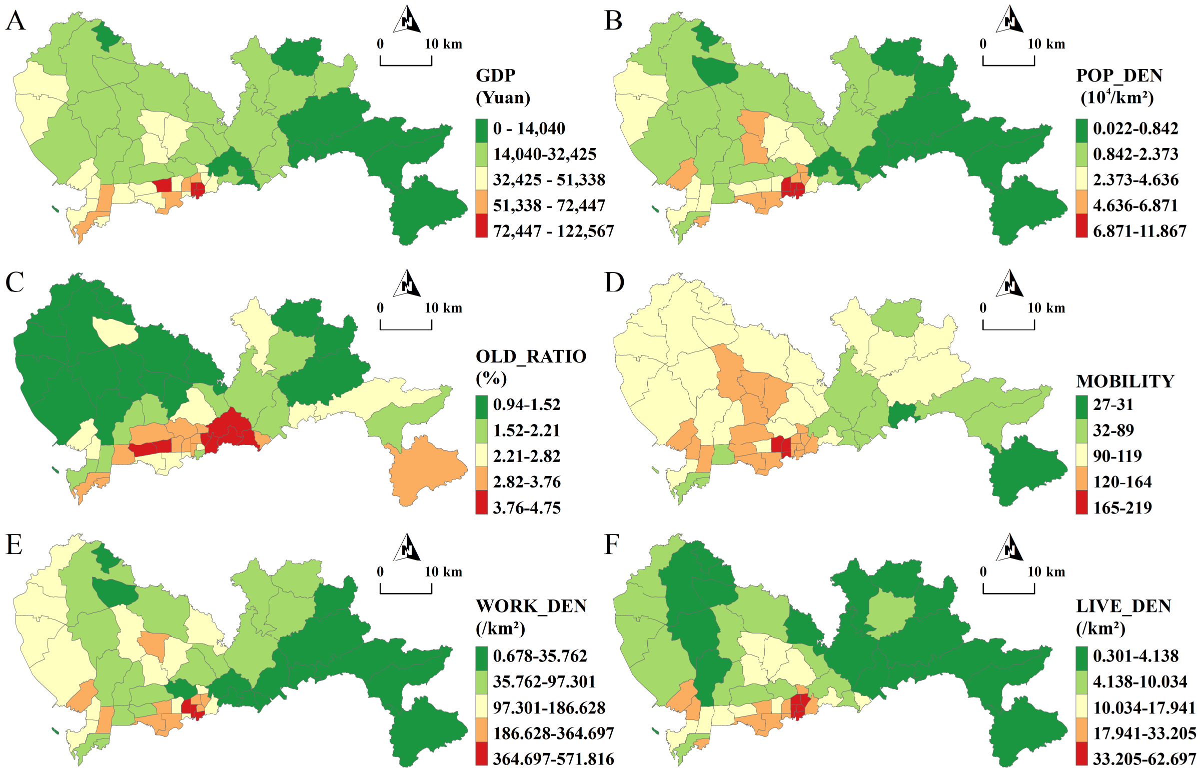

Figure 11. Spatial distribution of determinants in Shenzhen, including GDP (**A**), POP_DEN (**B**), OLD_RATIO (**C**), MOBILITY (**D**), WORK_DEN (**E**), LIVE_DEN (**F**).

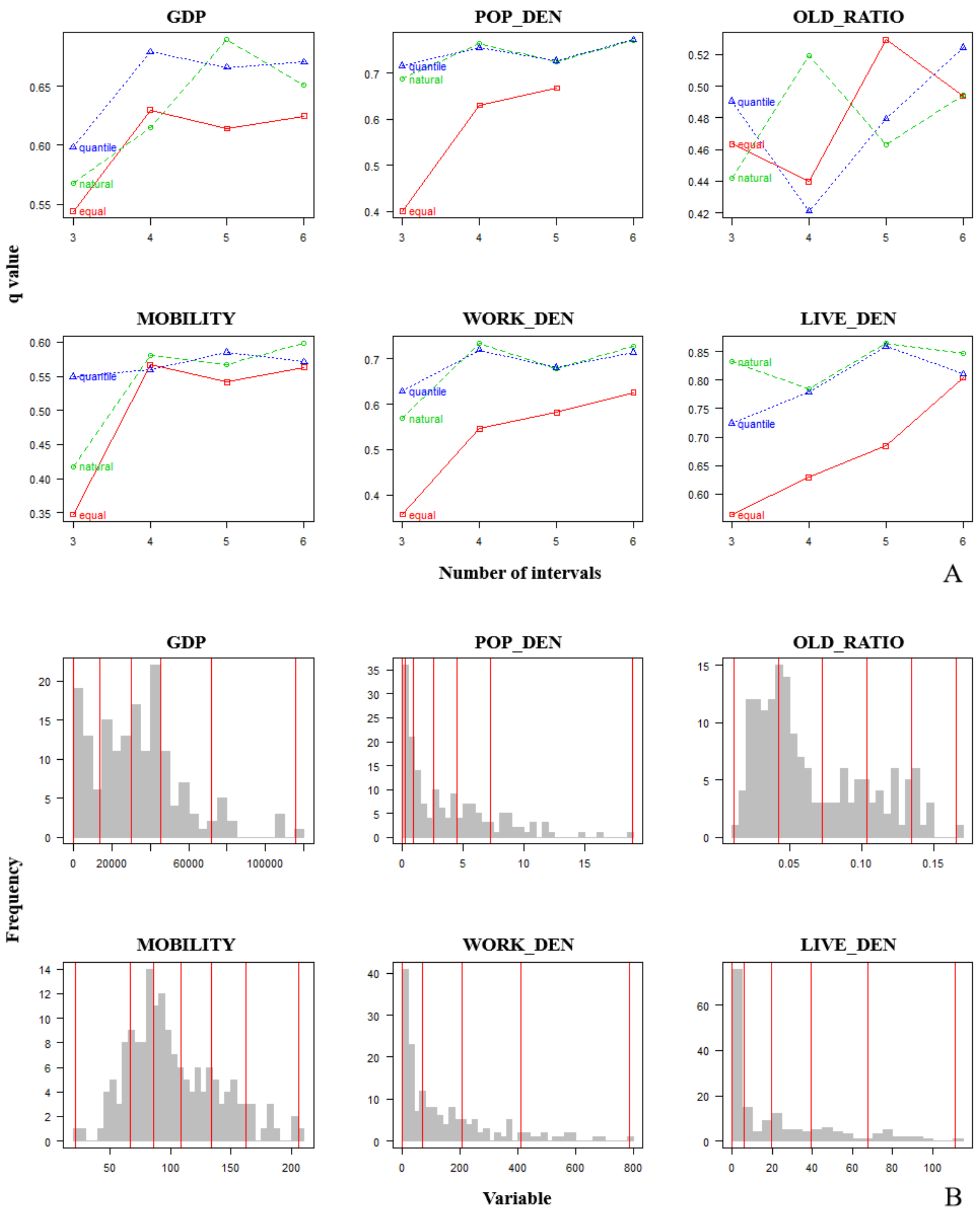

Figure 12. Optimal discretization of determinants in Guangzhou: discretization methods (**A**) and number of intervals (**B**).

Results of nine combinations of three discretization methods (quantile, natural, and equal) and three interval numbers (4–6) were compared, and the combination with the highest q value was output as the optimal discretization. The optimal discretization for each variable in Guangzhou and Shenzhen are listed in Table 2. It hints that the optimal discretization results of variables were associated with the data distribution and the consistency of the spatial pattern with the AED equity, rather than the absolute q value.

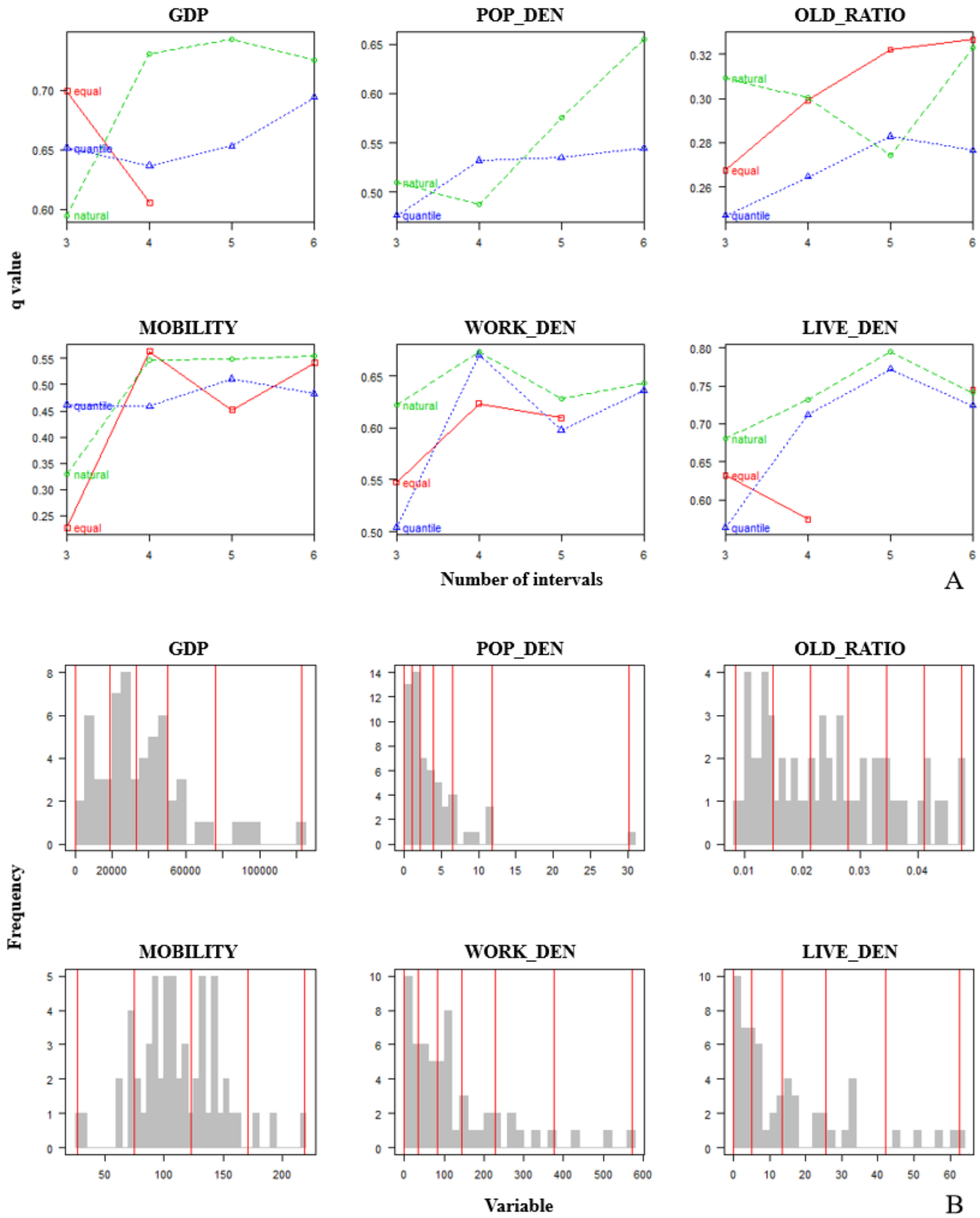

Figure 13. Optimal discretization of determinants in Shenzhen: discretization methods (**A**) and number of intervals (**B**).

3.4. Determinants of AED Equity Using the OPGD Model

The scatter plots of AED equity and selected determinants in Guangzhou and Shenzhen are presented in Figure 14, which indicate the correlation relationships. Six selected variables were found to be significantly and positively associated with AED equity. Among the variables in the Guangzhou case, LIVE_DEN was the variable with the highest Pearson's R (0.869), followed by POP_DEN (0.825), WORK_DEN (0.788), GDP (0.768), MOBILITY (0.727), and OLD_RATIO (0.698). In the Shenzhen case, LIVE_DEN was also the variable with the highest Pearson's R (0.844), followed by GDP (0.842), WORK_DEN (0.821), MOBILITY (0.7), OLD_RATIO (0.525), and POP_DEN (0.427).

Table 2. Optimal discretization of each determinant.

City	Variable	Discretization Method	No. of Intervals
Guangzhou	GDP	Quantile	4
	POP_DEN	Quantile	6
	OLD_RATIO	Natural	4
	MOBILITY	Natural	6
	WORK_DEN	Natural	4
	LIVE_DEN	Quantile	5
Shenzhen	GDP	Natural	5
	POP_DEN	Natural	6
	OLD_RATIO	Equal	6
	MOBILITY	Natural	6
	WORK_DEN	Natural	6
	LIVE_DEN	Quantile	5

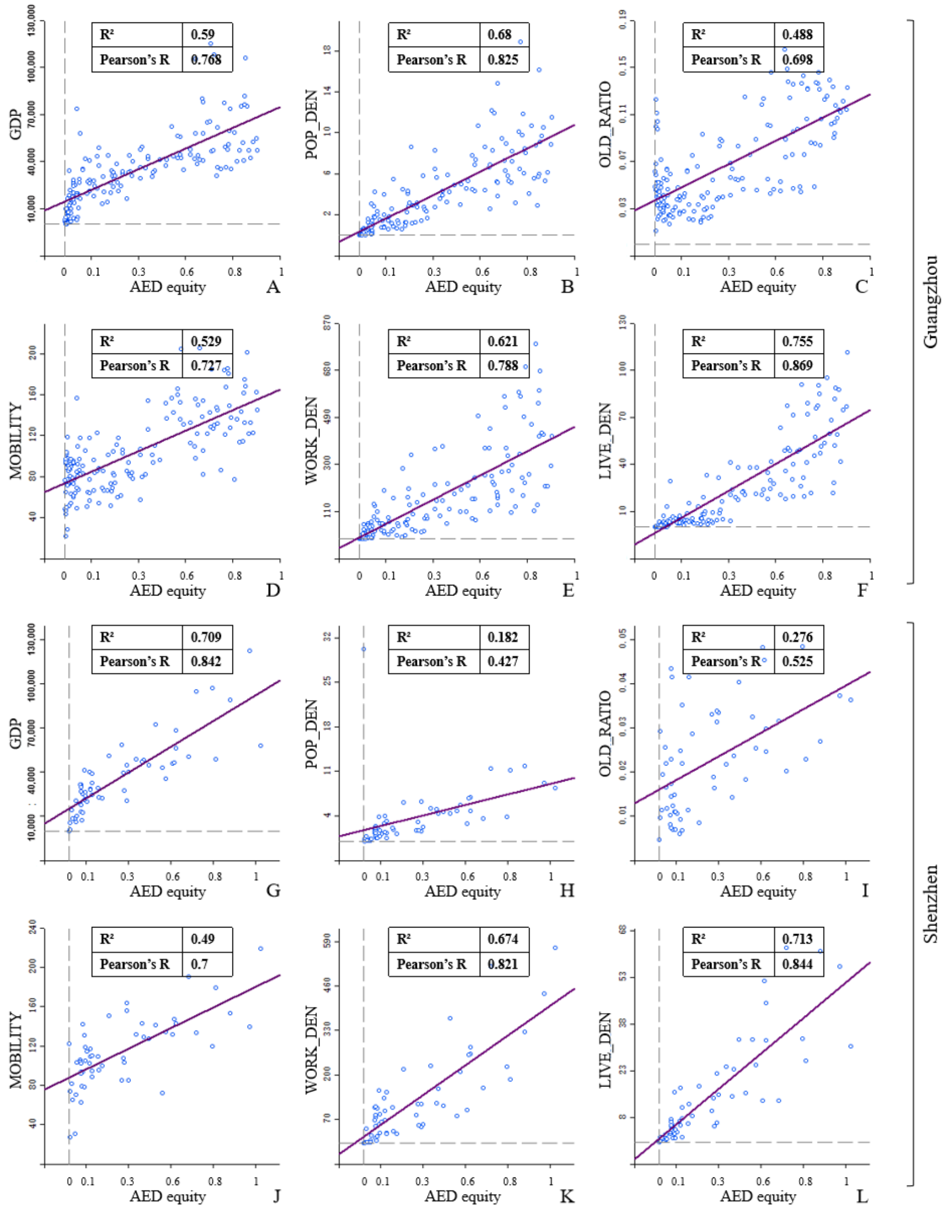

Figure 14. Scatter plots of AED equity and selected determinants including GDP (**A**,**G**), POP_DEN (**B**,**H**), OLD_RATIO (**C**,**I**), MOBILITY (**D**,**J**), WORK_DEN (**E**,**K**), LIVE_DEN (**F**,**L**).

The individual effects of each determinant on AED equity in Guangzhou and Shenzhen (results of factor detector) are shown in Figure 15. The effects of the six determinants selected for AED equity in Guangzhou and Shenzhen were significant with $p < 0.001$, indicating that the introduction of the OPGD model in AED equity analysis is feasible.

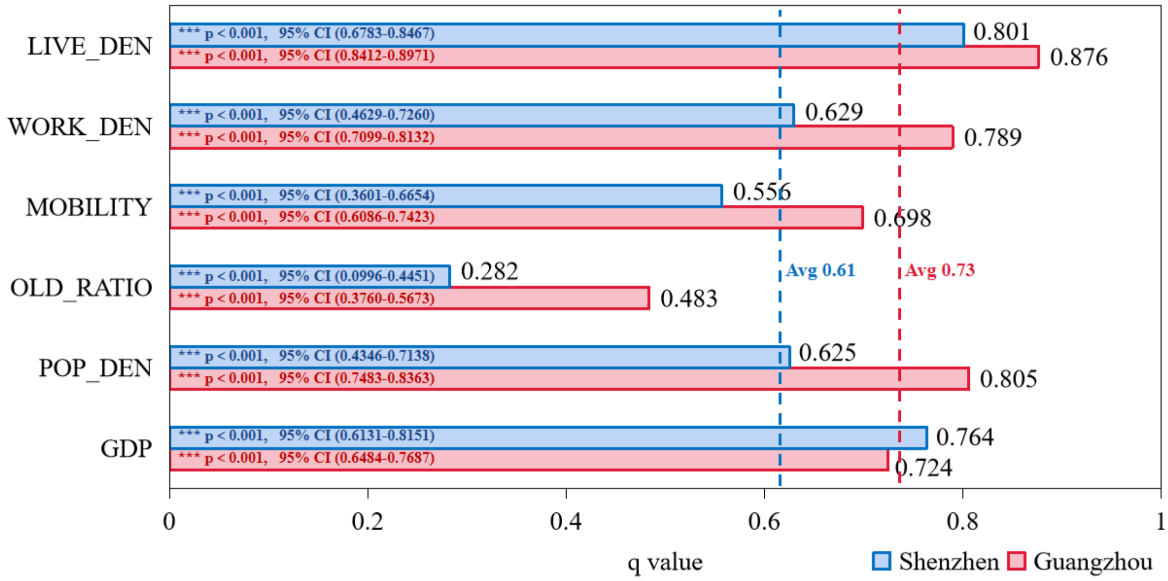

Figure 15. Results of factor detector model in Guangzhou and Shenzhen (individual effect of each factor on AED equity). (*** indicates significance at the level of p-value < 0.001).

3.4.1. Individual Effect of Each Determinant on AED Equity

In general, the average explanatory power of determinants for AED equity in Guangzhou (average q value = 0.73) was higher than that in Shenzhen (average q value = 0.61). According to the geographical detector model, determinants explained 73% of the variance of AED equity distribution in Guangzhou on average, which was 19.7% higher than that in Shenzhen. In the Guangzhou case, LIVE_DEN was the determinant with the highest q value (0.876), followed by POP_DEN (0.805), WORK_DEN (0.789), GDP (0.724), MOBILITY (0.698), and OLD_RATIO (0.483). In the Shenzhen case, LIVE_DEN was also the determinant with the highest q value (0.801), followed by GDP (0.764), WORK_DEN (0.629), POP_DEN (0.625), MOBILITY (0.556), and OLD_RATIO (0.282). Among these variables, LIVE_DEN, POP_DEN, and WORK_DEN were above average in Guangzhou, and LIVE_DEN, GDP, and WORK_DEN were above average in Shenzhen, which illustrates that these were the major determinants of AED equity in Guangzhou and Shenzhen from the perspective of individual effect.

In the model results, LIVE_DEN and GDP reflect the universality of the two cities. These two variables are not only the top two variables with q values in the two models of Guangzhou and Shenzhen, but also the two variables with the closest q values in the two models. The other four variables reflect individuality in the impact on AED equity. These differences indicate that this factor plays a different role in AED equity in the two cities.

Among the variables, LIVE_DEN and WORK_DEN reflect the two most central functions of cities: housing and employment [38,44]. The daily behaviors and activities of residents are mainly job–residence behaviors [38,45,46]. Therefore, employment centers such as Zhujiang New Town, Guangzhou and Huaqiangbei, Shenzhen and residential centers such as Yuexiu District, Guangzhou and Luohu District, Shenzhen usually have higher population density and activity frequency, which will increase the possibility of emergencies. To provide better emergency services, AED facilities are more densely located in these areas [9,10,13]. In terms of LIVE_DEN, the density of residence community was the most essential determinant with the strongest explanatory power, explaining 87.6% and

80.1% of the variance of AED equity in Guangzhou and Shenzhen, respectively. Residence community is the most common and standardized urban residential agglomeration area at present, and it is the focus of consideration in the location planning of AED facilities. The reason why LIVE_DEN had a higher explanatory power than POP_DEN is that, especially in megacities such as Guangzhou and Shenzhen, not all the population lives in residence communities, and quite a part of the population lives in informal residential areas, such as urban villages in the center and industrial villages in the outer suburbs [47,48]. In the planning stage of AED facilities, most will give priority to residential areas in the center of the city where the population is concentrated. AED facility planning usually gives priority to residential areas in urban centers with a high concentration of residents [2,9,10,26]. In terms of WORK_DEN, the density of companies was the determinant with the second or third highest explanatory power ranking after LIVE_DEN, explaining 78.9% and 62.9% of the variance of AED equity in Guangzhou and Shenzhen, respectively. However, the impact mechanism of WORK_DEN on AED equity is different from that of LIVE_DEN. First, the business and office areas are more likely to have emergency needs due to the intensive nature of work activities [14,49]. Second, regional regulations require that AED facilities should be deployed in business areas to ensure rapid first aid services in the event of an emergency. In addition, some companies proactively deploy AED facilities to provide for the safety of employees and customers. Moreover, unlike residential areas, business areas typically face more diverse emergencies such as cardiac arrest, accident injury, and sudden illness. Therefore, the employment centers are distributed with a demand-matched supply of AED facilities (a high level of AED equity) to meet the high frequency and diverse emergency needs of occupational activities to ensure timely emergency assistance in the event of an emergency incident.

In terms of mobility, its influence on AED equity in Guangzhou was 25.5% higher than that in Shenzhen. This may be caused by the difference between Shenzhen's multi-center urban structure and Guangzhou's single-core urban structure [38,46]. Compared with traditional single-center cities, the development of Shenzhen pays more attention to multi-centralization, that is, several commercial, administrative, and cultural centers have been formed in the city, such as Futian Center, Nanshan Center, and Luohu Center. Specifically, the single core of Guangzhou is mainly distributed within a radius of 10 km, centered by Zhujiang New Town in Tianhe District, while the polycentric spatial distance of Shenzhen is greater than 20 km [40,46]. This kind of multi-center urban structure makes the economic and social activities of Shenzhen relatively dispersed in different areas; people can live, work, have entertainment and other aspects of more convenient activities in the region, reducing the demand for the central area. Therefore, the mobility of the population in different areas of Shenzhen may be more balanced, and there is no obvious "peak time" or "trough time" as in traditional single-center cities. In short, the spatial distribution of population, employment, and residence in Shenzhen is more even than in Guangzhou. That is, the demand side of AED facilities is distributed more evenly and dispersed in Shenzhen, while it is more concentrated in Guangzhou. This shows the impact of urban spatial structure on the supply and demand relationship of public service facilities and emergency medical facilities, that is, equity.

In terms of POP_DEN, its explanatory power reached 0.805 in Guangzhou, 28.8% higher than that in Shenzhen. It indicates that the current spatial pattern of AED equity is highly consistent with the local population density in Guangzhou. In fact, Shenzhen was higher than Guangzhou in terms of the number and distribution density of AEDs. This difference was due to the different stages of development of AED facilities in the two cities. First, Shenzhen is the first city in China to fully promote the installation of AED facilities, and so far, it is still leading the country. When AED facilities are set up from scratch, areas with high population density are often prioritized [10,13], and Guangzhou is currently in this stage. However, Shenzhen is now in the stage of further optimizing the allocation of AED resources, paying more attention to the uniform distribution of AED facilities in different areas to meet the city-wide emergency needs. Therefore, despite the high population density in Shenzhen, the optimal allocation of AEDs may make the distribution of AED facilities more balanced and reduce the influence of POP_DEN on AED equity.

In terms of OLD_RATIO, it was the determinant with the maximum difference in explanatory power between Guangzhou and Shenzhen, indicating the remarkable variation in the population structure characteristic of the two cities. The explanatory power of OLD_RATIO in Guangzhou was 71.3% higher than that in Shenzhen. As mentioned in Table 1, the proportion of the elderly was 6.5% and 2.4% in Guangzhou and Shenzhen, respectively. Guangzhou has a more serious aging population than Shenzhen [41], and older people often have higher health risks, including potential heart disease and other diseases [3]. To better protect the health of the elderly and cope with the emergencies of the elderly, more AED facilities need to be set up in the streets with a high degree of aging. Therefore, Guangzhou may pay more attention to the health and welfare of the elderly and formulate relevant policies to support health services for the elderly. The distribution of AED facilities may be influenced by policy inclination for those blocks with a higher aging rate to meet the emergency needs of the elderly.

In terms of GDP, it was the only determinant with stronger explanatory power on AED equity in Shenzhen than that in Guangzhou. It hints that Shenzhen, as a special zone and economic center in China, has a high level of economic development and resource investment, which may enable Shenzhen to invest more resources in the construction and layout of AED facilities and improve the number and density of AED facilities. In contrast, Guangzhou may invest relatively little resources in the construction of AED facilities, resulting in a relatively low number and density of AED facilities. Moreover, according to news reports, Shenzhen has a considerable number of AED facilities donated by local enterprises or businessmen and are deployed in local public places, which are often located in the blocks with higher local economic level.

3.4.2. Interactive Effect of Determinant Pairs on AED Equity

Figure 16 and Table 3 present the results of the interaction detector. The average joint q value of determinant pairs reached 0.878 and 0.807 in Guangzhou and Shenzhen, 20.3% and 32.2% higher than the average individual q values, which indicates that the results of the interaction detector model had stronger explanatory power than that of the factor detector model. In both the Guangzhou and Shenzhen cases, the interactive effects of 15 pairs of determinants on AED equity were found to be bivariate enhanced, which hints that the interactive effects between each pair of determinants was remarkably stronger than the individual effect of each determinant.

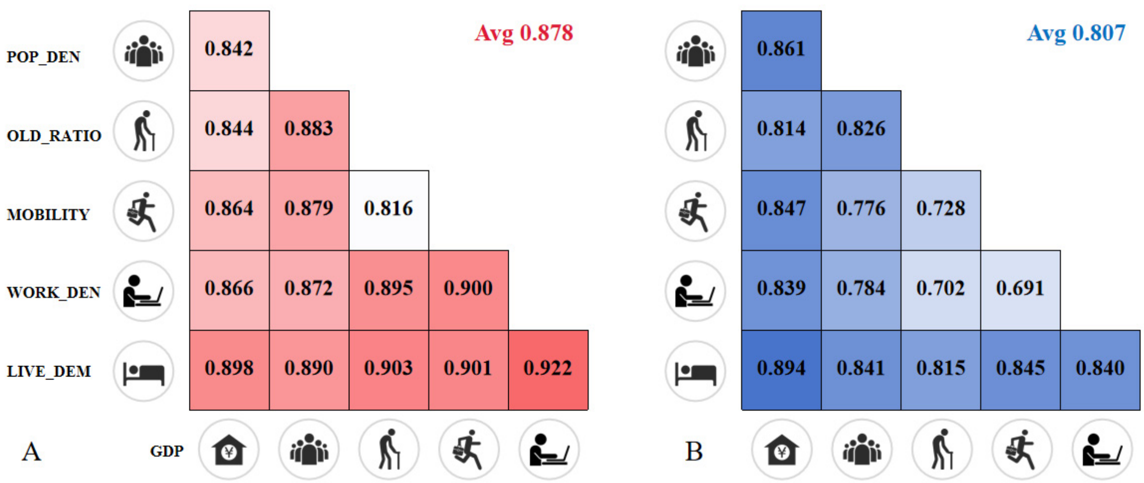

Figure 16. Results of the interaction detector model in Guangzhou (**A**) and Shenzhen (**B**) (interactive effects of factor pairs on AED equity).

Table 3. Top five pairs of determinants with high interactive explanatory power.

City	Rank	X_i	X_j	Joint q Value ($X_i \cap X_j$)	Variation Compared with X_i	Variation Compared with X_j
GZ	1	WORK_DEN	LIVE_DEN	0.922	16.86%	5.25%
	2	OLD_RATIO	LIVE_DEN	0.903	87.04%	3.13%
	3	MOBILITY	LIVE_DEN	0.901	29.06%	2.83%
	4	MOBILITY	WORK_DEN	0.900	28.87%	14.01%
	5	GDP	LIVE_DEN	0.898	24.07%	2.54%
SZ	1	GDP	LIVE_DEN	0.894	34.59%	5.02%
	2	GDP	POP_DEN	0.861	51.96%	5.48%
	3	GDP	MOBILITY	0.847	10.92%	52.42%
	4	MOBILITY	LIVE_DEN	0.845	12.69%	37.75%
	5	POP_DEN	LIVE_DEN	0.841	17.07%	11.66%

Results of the interaction detector model can be interpreted from two perspectives: the joint q values of determinant pairs and the variations of the joint q values compared with the individual q values of each determinant (Table 3). The joint q value indicates the interactive effect of a pair of determinants on AED equity, and the variation reflects the difference between the joint q value and individual q value when one determinant interacts with another determinant. In the results of this study, all variations were manifested as enhancements. To better understand the interaction between determinants affecting AED equity, the scatter plots between the determinants are presented in Figure 17.

The top three pairs of determinants were associated with LIVE_DEN in Guangzhou. The joint q value of WORK_DEN and LIVE_DEN was the highest, reaching 0.922, which indicates that these two determinants interactively explained 92.2% of the variance in AED equity in Guangzhou. This implies that the layout of the few AED facilities in Guangzhou is not as uniform as Shenzhen and can only tend to be set in the centers of the districts and blocks. In Guangzhou, there is a significant positive correlation between the density of residential quarters and the density of companies in each block (Figure 17A). The city center and the local centers are the areas that meet high levels of LIVE_DEN, WORK_DEN, and MOBILITY at the same time. This also shows once again that the layout of AED facilities in Guangzhou is still in its preliminary stage.

Uniquely, the interaction between OLD_RATIO and LIVE_DEN ranked second in Guangzhou, while OLD_RATIO did not appear in the top five rankings in Shenzhen. The enhancement of the interaction between OLD_RATIO and LIVE_DEN compared with the individual q value of OLD_RATIO was the strongest (+87.04%) in this study. That is, high-aging blocks explained only 48.3% of the AED equity, while high-aging and dense residential blocks explained 90.3% of the variance in AED equity distribution. It indicates that in addition to the city center, the residential areas with a higher aging population are areas where the supply and demand of AED facilities are more balanced, that is, more equitable.

Differently, the top three pairs of determinants were associated with GDP in Shenzhen with an average joint q value of 0.867, which reflects that the distribution pattern of AED facilities in Shenzhen was highly linked to the level of local economic development. The interaction between GDP and LIVE_DEN was the highest with a joint q value of 0.894, which indicates that these two determinants interactively explained 89.4% of the variance in AED equity in Shenzhen. GDP and LIVE_DEN were also the determinants with the top two individual q values in Shenzhen. It reflects that based on high local economic level, high-density residential areas, densely populated areas, and areas with strong mobility are where, AED distribution was relatively equitable in Shenzhen. The enhancements of GDP∩POP_DEN and GDP∩MOBILITY compared with GDP (+51.96%) and MOBILITY (+52.42%), respectively, were the highest, above 50% in Shenzhen, which illustrates the importance of local economic development and population density as well as mobility on AED equity.

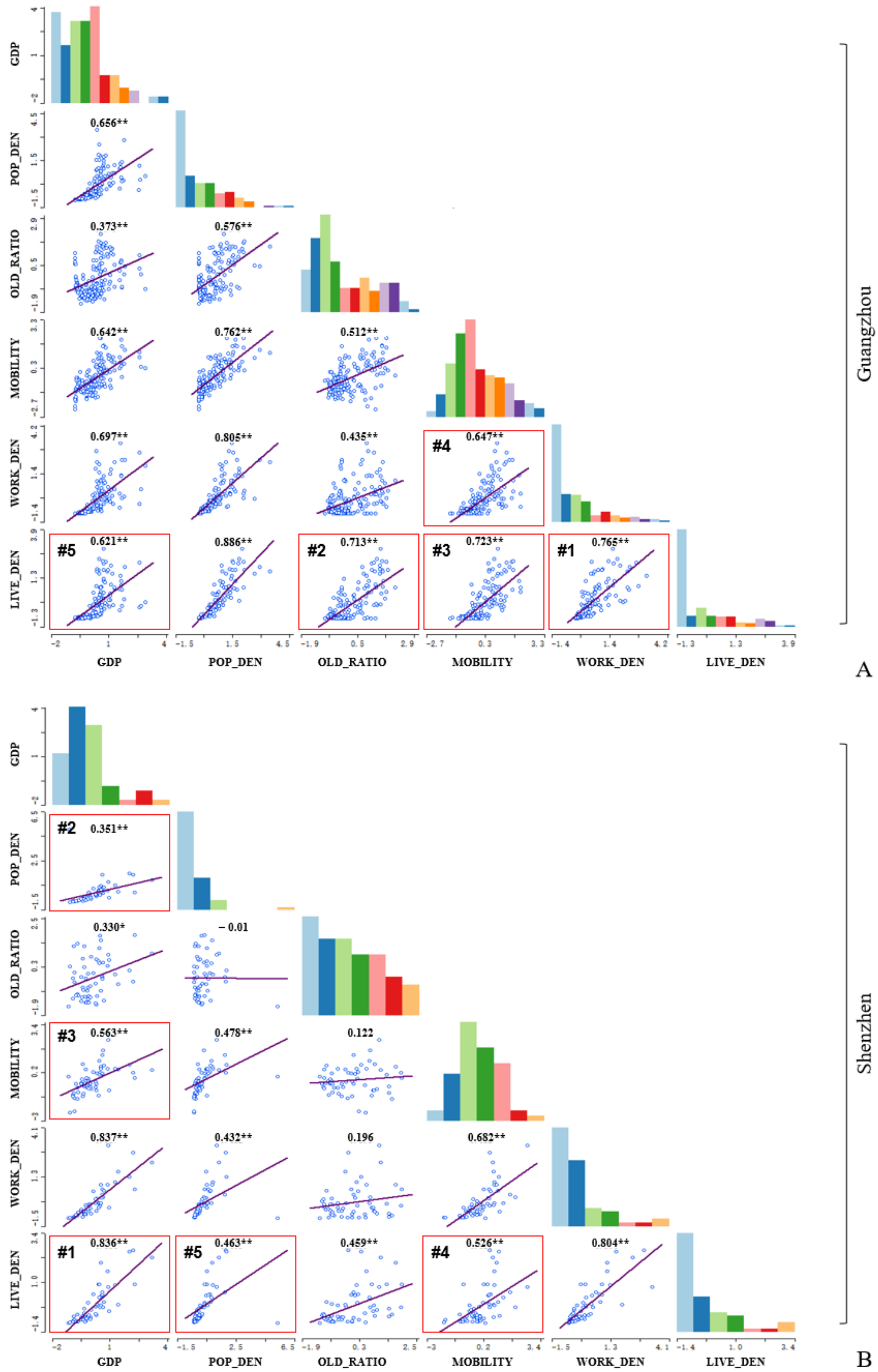

Figure 17. Scatter plots between determinants in Guangzhou (**A**) and Shenzhen (**B**). #1-5 are the scatter plots of the top five pairs of determinants in the interaction detector model. (** and * indicate significance at the level of *p*-value < 0.01 and *p*-value < 0.05).

3.5. Implications

There was a huge gap in the number, equity, and its determinants of AEDs in Guangzhou and Shenzhen. Because of the sheer preponderance of quantity, Shenzhen was better than Guangzhou in the number, distribution density, and overall and local equity of AEDs. The results of the OPGD model reflect that Guangzhou and Shenzhen had significant differences in the implementation of the promotion of AED facilities. Guangzhou was still in the preliminary planning and layout stage from scratch, while Shenzhen was already in the optimization and densifying layout stage. AED is a public emergency medical facility, which is costly and in urgent need. In recent years, major cities in China have successively set up AED facilities and gradually expanded the coverage. When AEDs begin to be deployed in a city, it is usually dominated by the local municipal government, and the first batch of devices are mostly deployed in densely populated residential areas. When the AED configuration work has been carried out for a period, the subsequent AED facility planning, that is, the gradual optimization stage, is often delegated to the local block government and enterprises. Currently, because the initiative of AED facility planning belongs to the local government, the block with a high economic development level provides more taxes, so there is a more generous financial budget for investing in the construction and improvement of local infrastructure, which includes AEDs. In addition, some local merchants, chambers of commerce, and enterprises will improve their social reputation by donating AED equipment. Therefore, the strong explanatory power of local economic development level on AED equity in Shenzhen is a significant feature that distinguishes Guangzhou.

Theoretically, this study provides a scientific and technical framework for the evaluation of service level and equity of urban AED facilities and its influencing factors, which is conducive to the planning and management of other urban public service facilities other than medical facilities. The results of this study are conducive to understanding the equity of the current AED facility layout and its socio-economic influencing factors through the case study of two megacities in China, to provide implications for relevant policies and management. First, for cities with AED facilities from scratch to existence, the first batch of equipment should focus on areas with high residential density, population density, and employment density. The reasonable number of AEDs in public places can be determined according to the principle of allocating 100 to 200 AEDs per 100,000 people [4]. In addition, this study suggests that governments should reform the mechanism from planning to implementation of AED facilities and should gradually try to devolve such planning and implementation to local governments to introduce more subjects of planning, implementation, investment, management, and other links besides the government. Secondly, encouraging the local government to increase the number of AEDs according to the actual situation and encouraging enterprises and individuals to donate to relevant institutions (such as the local Red Cross Society) to support the development of first aid are important measures to improve the level of AED allocation and application.

OHCA cases are the rescue objects of AED facilities, and the lack of application of OHCA case data is an urgent problem to be solved in the future of this study. The next phase of work will revolve around AED configuration studies based on OHCA data. First, based on OHCA case data, it is possible to assess the potential needs of an area and then decide how many AEDs to deploy. This enables better coverage, response, and handling of OHCA events. Second, case data can reflect the relationship between response time and successful resuscitation rates. By analyzing OHCA case data, it is possible to find high incidence locations and time periods, so that emergency response and training can be strengthened in these areas and time periods to improve the success rate of first aid. Third, through continuous monitoring of OHCA case data, the effectiveness and impact of AED facilities can be assessed and the layout and arrangement can be adjusted in a timely manner. This helps to provide more timely and effective emergency services and reduce death and disability from cardiac arrest.

According to the correlation difference between AED equity and various factors obtained by this research model, AED facilities can be further optimized and planned in the future from the perspective of equity. First, optimize the location of AED facilities. Based on the model results of this study, determine which factors are highly correlated with the demand for AED facilities. For example, if population density is positively correlated with demand for AED facilities, we can prioritize placing facilities in densely populated areas. In this way, the location of AED facilities can be optimized to better meet the needs of the population. Second, fill in the gaps. The results of this study may indicate a gap in AED facilities in some areas. In this case, these blank areas can be considered as priority areas to fill the gaps in the layout of the facility. Proposals can be made to build new AED facilities in these areas or to adapt existing facilities. Third, consider population mobility and transport networks. Population mobility and transportation networks are important factors in determining the accessibility of AED facilities. Based on the results of this study, it is possible to determine which factors are related to population mobility and transportation networks. Although no traffic-related variables were included in this study, this will be addressed in future work. These factors can include public transport coverage, road network density, etc. By considering these factors, recommendations can be made to improve the accessibility of AED facilities based on transportation convenience to ensure that people can reach the facilities as soon as possible in an emergency. Fourth, consider the community economic level and the proportion of the elderly. The results of this study may indicate that the economic level of the community and the proportion of the elderly are related to the demand for AED facilities. These factors can be considered when planning or optimizing AED facilities, and recommendations can be made based on community characteristics and needs. For example, in economically underdeveloped places where elderly people congregate, build more AED facilities or increase facility capacity to meet demand. Fifth, evaluate and update regularly. The needs and demographics of AED facilities change over time, so it is necessary to regularly evaluate and update facility planning and optimization. As the population changes and social development evolves, the layout of facilities may need to be adjusted and optimized accordingly.

4. Conclusions

The contribution of this study to the relevant literature is to simultaneously measure the equity of AED facilities in two megacities by means of big data and quantify the determinants of equity to make a comprehensive comparative analysis. This study collected relatively comprehensive AED data based on the WeChat applet and evaluated the differences in AED facilities in Guangzhou and Shenzhen on the aspects of quantity, distribution, equity, and its determinants by using the Gini coefficient, Lorenz curve, and the OPGD model. Results show that the number of AEDs in Shenzhen was about eight-times that in Guangzhou. The distribution of AEDs in Shenzhen was more equitable with a global Gini of 0.347, higher than that in Guangzhou with a global Gini of 0.504. As for the determinants of AED equity, residential density was the most significant determinant in both Guangzhou and Shenzhen from the perspective of individual effect on AED equity. Differently, due to the aging population in Guangzhou, the proportion of the elderly in blocks was influential to local AED equity. While, the local economic development level was crucial to local AED equity in Shenzhen. The results of the interaction detector model illustrate that relatively equitable AED distributions were found in the high-density residential areas with a balance of employment and housing, high-aging residential areas, and high-mobility residential areas in Guangzhou. The area with a high level of local economic development, dense population, and large mobility was the area with relatively equitable distribution of AEDs in Shenzhen. The results of this paper are conducive to understanding the equity of AEDs and its socio-economic determinants, providing scientific reference for the optimization and management of AEDs.

Despite the advantages of this study, some aspects need to be addressed in the future. First, we only analyzed the AED equity in the whole society in Guangzhou and Shenzhen and did not involve the equity in different social groups, which should be expanded in the future. Secondly, OHCA case data should be considered to accurately evaluate the social coverage of the distribution of AED facilities in the future. Third, though the spatial distribution of AED equity at block level was uncovered in this study, the spatially varying associations between influencing factors and AED equity should be considered in future work by using the geographical weighted regression [50–52].

Author Contributions: Conceptualization, Shunyi Liao and Feng Gao; methodology, Shunyi Liao and Feng Gao; software, Shunyi Liao and Feng Gao; validation, Feng Gao. Lei Feng, Jiemin Wu, Zexia Wang and Wangyang Chen; formal analysis, Shunyi Liao and Feng Gao; investigation, Shunyi Liao, Feng Gao, Lei Feng, Jiemin Wu, Zexia Wang and Wangyang Chen; resources, Feng Gao; data curation, Shunyi Liao and Feng Gao; writing—original draft preparation, Shunyi Liao and Feng Gao; writing–review & ed-iting, Shunyi Liao and Feng Gao; visualization, Shunyi Liao and Feng Gao; supervision, Feng Gao; project administration, Feng Gao; funding acquisition, Feng Gao. All authors have read and agreed to the published version of the manuscript.

Funding: The completion of this work was supported by the Collaborative Innovation Center for Natural Resources Planning and Marine Technology of Guangzhou (No.2023B04J0301), Key-Area Research and Development Program of Guangdong Province (No.2020B0101130009), and Guangdong Enterprise Key Laboratory for Urban Sensing, Monitoring and Early Warning (No.2020B121202019).

Data Availability Statement: Data are unavailable due to privacy reasons.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Kitamura, T.; Iwami, T.; Kawamura, T.; Nagao, K.; Tanaka, H.; Hiraide, A. Nationwide Public-Access Defibrillation in Japan. *N. Engl. J. Med.* **2010**, *362*, 994–1004. [CrossRef] [PubMed]
2. Feero, S.; Hedges, J.R.; Stevens, P. Demographics of Cardiac Arrest: Association with Residence in a Low-Income Area. *Acad. Emerg. Med.* **1995**, *2*, 11–16. [CrossRef] [PubMed]
3. Su, Y.-J.; Lai, Y.-C.; Chen, C.-C.; Chang, W.-H. Out-of-Hospital Cardiac Arrest in The Elderly. *Int. J. Gerontol.* **2008**, *2*, 67–71. [CrossRef]
4. Folke, F.; Lippert, F.K.; Nielsen, S.L.; Gislason, G.H.; Hansen, M.L.; Schramm, T.K.; Sørensen, R.; Fosbøl, E.L.; Andersen, S.S.; Rasmussen, S.; et al. Location of Cardiac Arrest in a City Center: Strategic Placement of Automated External Defibrillators in Public Locations. *Circulation* **2009**, *120*, 510–517. [CrossRef]
5. Brooks, S.C.; Hsu, J.H.; Tang, S.K.; Jeyakumar, R.; Chan, T.C.Y. Determining Risk for Out-of-Hospital Cardiac Arrest by Location Type in a Canadian Urban Setting to Guide Future Public Access Defibrillator Placement. *Ann. Emerg. Med.* **2013**, *61*, 530–538.e2. [CrossRef]
6. Deakin, C.D.; Shewry, E.; Gray, H.H. Public Access Defibrillation Remains out of Reach for Most Victims of Out-of-Hospital Sudden Cardiac Arrest. *Heart* **2014**, *100*, 619–623. [CrossRef]
7. Boutilier, J.J.; Brooks, S.C.; Janmohamed, A.; Byers, A.; Buick, J.E.; Zhan, C.; Schoellig, A.P.; Cheskes, S.; Morrison, L.J.; Chan, T.C.Y. Optimizing a Drone Network to Deliver Automated External Defibrillators. *Circulation* **2017**, *135*, 2454–2465. [CrossRef] [PubMed]
8. Aeby, D.; Staeger, P.; Dami, F. How to Improve Automated External Defibrillator Placement for Out-of-Hospital Cardiac Arrests: A Case Study. *PLoS ONE* **2021**, *16*, e0250591. [CrossRef]
9. Lin, B.-C.; Chen, C.-W.; Chen, C.-C.; Kuo, C.-L.; Fan, I.; Ho, C.-K.; Liu, I.-C.; Chan, T.-C. Spatial Decision on Allocating Automated External Defibrillators (AED) in Communities by Multi-Criterion Two-Step Floating Catchment Area (MC2SFCA). *Int. J. Health Geogr.* **2016**, *15*, 17. [CrossRef]
10. Chen, G.; Widener, M.J.; Zhu, M.; Wang, C.C. Identification of Priority Areas for Public-Access Automated External Defibrillators (AEDs) in Metropolitan Areas: A Case Study in Hangzhou, China. *Appl. Geogr.* **2023**, *154*, 102922. [CrossRef]
11. China Association for the Promotion of International Exchange of Medical Care Chest Pain Branch. Report on Cardiac Arrest and Cardiopulmonary Resuscitation in China (2022 Edition). *Biomed. Environ. Sci.* **2023**, *36*, 669–701.
12. Hu, S. Report on Cardiovascular Health and Diseases in China 2019: An Updated Summary. *Chin. Circ. J.* **2020**, *35*, 3969.
13. Bonnet, B.; Gama Dessavre, D.; Kraus, K.; Ramirez-Marquez, J.E. Optimal Placement of Public-Access AEDs in Urban Environments. *Comput. Ind. Eng.* **2015**, *90*, 269–280. [CrossRef]
14. Tsai, Y.-S.; Ko, P.C.-I.; Huang, C.-Y.; Wen, T.-H. Optimizing Locations for the Installation of Automated External Defibrillators (AEDs) in Urban Public Streets through the Use of Spatial and Temporal Weighting Schemes. *Appl. Geogr.* **2012**, *35*, 394–404. [CrossRef]
15. Fan, M.; Fan, K.; Leung, L. Walking Route–Based Calculation Is Recommended for Optimizing Deployment of Publicly Accessible Defibrillators in Urban Cities. *JAHA* **2020**, *9*, e014398. [CrossRef]

16. Gianotto-Oliveira, R.; Gonzalez, M.M.; Vianna, C.B.; Monteiro Alves, M.; Timerman, S.; Kalil Filho, R.; Kern, K.B. Survival After Ventricular Fibrillation Cardiac Arrest in the Sao Paulo Metropolitan Subway System: First Successful Targeted Automated External Defibrillator (AED) Program in Latin America. *JAHA* **2015**, *4*, e002185. [CrossRef]
17. Hare, T.S.; Barcus, H.R. Geographical Accessibility and Kentucky's Heart-Related Hospital Services. *Appl. Geogr.* **2007**, *27*, 181–205. [CrossRef]
18. Yeung, J.; Okamoto, D.; Soar, J.; Perkins, G.D. AED Training and Its Impact on Skill Acquisition, Retention and Performance—A Systematic Review of Alternative Training Methods. *Resuscitation* **2011**, *82*, 657–664. [CrossRef]
19. Sun, C.L.F.; Karlsson, L.; Torp-Pedersen, C.; Morrison, L.J.; Folke, F.; Chan, T.C.Y. Spatiotemporal AED Optimization Is Generalizable. *Resuscitation* **2018**, *131*, 101–107. [CrossRef]
20. Dao, T.H.D.; Zhou, Y.; Thill, J.-C.; Delmelle, E. Spatio-Temporal Location Modeling in a 3D Indoor Environment: The Case of AEDs as Emergency Medical Devices. *Int. J. Geogr. Inf. Sci.* **2012**, *26*, 469–494. [CrossRef]
21. Zhang, J.; Mu, L.; Zhang, D.; Rajbhandari-Thapa, J.; Chen, Z.; Pagán, J.A.; Li, Y.; Son, H.; Liu, J. Spatiotemporal Optimization for the Placement of Automated External Defibrillators Using Mobile Phone Data. *Int. J. Geo Inf.* **2023**, *12*, 91. [CrossRef] [PubMed]
22. Tsukigase, K.; Tanaka, H.; Takyu, H. Mismatch between Sites of Incidence of Out-of-Hospital Cardiac Arrest and Locations of Installed Automated External Defibrillator in the Tokyo Metropolitan Area. *World J. Cardiovasc. Dis.* **2017**, *07*, 185–194. [CrossRef]
23. Tierney, N.J.; Reinhold, H.J.; Mira, A.; Weiser, M.; Burkart, R.; Benvenuti, C.; Auricchio, A. Novel Relocation Methods for Automatic External Defibrillator Improve Out-of-Hospital Cardiac Arrest Coverage under Limited Resources. *Resuscitation* **2018**, *125*, 83–89. [CrossRef]
24. Purahong, B.; Anuwongpinit, T.; Juhong, A.; Kanjanasurat, I.; Pintaviooj, C. Medical Drone Managing System for Automated External Defibrillator Delivery Service. *Drones* **2022**, *6*, 93. [CrossRef]
25. Pollack, R.A.; Brown, S.P.; Rea, T.; Aufderheide, T.; Barbic, D.; Buick, J.E.; Christenson, J.; Idris, A.H.; Jasti, J.; Kampp, M.; et al. Impact of Bystander Automated External Defibrillator Use on Survival and Functional Outcomes in Shockable Observed Public Cardiac Arrests. *Circulation* **2018**, *137*, 2104–2113. [CrossRef]
26. Lwanga, A.; Garcia-Sayan, E.; Lwanga, S.; Karreman, E.; Mohamed, A. Automated External Defibrillators and Survival After Nonresidential Out of Hospital Cardiac Arrest in a Small North American City. *Am. J. Cardiol.* **2017**, *119*, 1979–1982. [CrossRef]
27. Lorenzo, G.; Maria Antonia, B.; Piero Maria, B.; Andrea, P.; Guido Francesco, V.; Enrico Gianluca, C. Development of a Novel Framework to Propose New Strategies for Automated External Defibrillators Deployment Targeting Residential Out-of-Hospital Cardiac Arrests: Application to the City of Milan. *Int. J. Geo Inf.* **2020**, *9*, 491. [CrossRef]
28. Deng, X.; Gao, F.; Liao, S.; Liu, Y.; Chen, W. Spatiotemporal Evolution Patterns of Urban Heat Island and Its Relationship with Urbanization in Guangdong-Hong Kong-Macao Greater Bay Area of China from 2000 to 2020. *Ecol. Indic.* **2023**, *146*, 109817. [CrossRef]
29. Niu, Y.; Chen, R.; Liu, C.; Ran, P.; Chen, A.; Chen, X.; Kan, H. The Association between Ambient Temperature and Out-of-Hospital Cardiac Arrest in Guangzhou, China. *Sci. Total Environ.* **2016**, *572*, 114–118. [CrossRef]
30. Dai, X.; He, X.; Zhou, Z.; Chen, J.; Wei, S.; Chen, R.; Yang, B.; Feng, W.; Shan, A.; Wu, T.; et al. Short-Term Effects of Air Pollution on out-of-Hospital Cardiac Arrest in Shenzhen, China. *Int. J. Cardiol.* **2015**, *192*, 56–60. [CrossRef]
31. Song, Y.; Chen, B.; Ho, H.C.; Kwan, M.-P.; Liu, D.; Wang, F.; Wang, J.; Cai, J.; Li, X.; Xu, Y.; et al. Observed Inequality in Urban Greenspace Exposure in China. *Environ. Int.* **2021**, *156*, 106778. [CrossRef]
32. Chen, Z.; Li, P.; Jin, Y.; Jin, Y.; Chen, J.; Li, W.; Song, X.; Shibasaki, R.; Chen, M.; Yan, D.; et al. Using Mobile Phone Big Data to Identify Inequity of Artificial Light at Night Exposure: A Case Study in Tokyo. *Cities* **2022**, *128*, 103803. [CrossRef]
33. Li, C.-E.; Lin, Z.-H.; Hsu, Y.-Y.; Kuo, N.-W. Lessons from COVID-19 Pandemic: Analysis of Unequal Access to Food Stores Using the Gini Coefficient. *Cities* **2023**, *135*, 104217. [CrossRef]
34. Zhang, D.; Zhang, G.; Zhou, C. Differences in Accessibility of Public Health Facilities in Hierarchical Municipalities and the Spatial Pattern Characteristics of Their Services in Doumen District, China. *Land* **2021**, *10*, 1249. [CrossRef]
35. Yu, P.; Jian, I.Y.; Yung, E.H.K.; Chan, E.H.W.; Wong, M.S.; Chen, Y. Spatial Vertical Equity in Public General Hospitals: Towards a Sustainable Healthcare System. *Land* **2023**, *12*, 1498. [CrossRef]
36. Song, Y.; Wang, J.; Ge, Y.; Xu, C. An Optimal Parameters-Based Geographical Detector Model Enhances Geographic Characteristics of Explanatory Variables for Spatial Heterogeneity Analysis: Cases with Different Types of Spatial Data. *GIScience Remote Sens.* **2020**, *57*, 593–610. [CrossRef]
37. Wang, J.; Li, X.; Christakos, G.; Liao, Y.; Zhang, T.; Gu, X.; Zheng, X. Geographical Detectors-Based Health Risk Assessment and Its Application in the Neural Tube Defects Study of the Heshun Region, China. *Int. J. Geogr. Inf. Sci.* **2010**, *24*, 107–127. [CrossRef]
38. Zhou, X.; Yeh, A.G.O. Understanding the Modifiable Areal Unit Problem and Identifying Appropriate Spatial Unit in Jobs–Housing Balance and Employment Self-containment Using Big Data. *Transportation* **2021**, *48*, 18. [CrossRef]
39. Gao, F.; Li, S.; Tan, Z.; Wu, Z.; Zhang, X.; Huang, G.; Huang, Z. Understanding the Modifiable Areal Unit Problem in Dockless Bike Sharing Usage and Exploring the Interactive Effects of Built Environment Factors. *Int. J. Geogr. Inf. Sci.* **2021**, *35*, 1905–1925. [CrossRef]
40. Gao, F.; Deng, X.; Liao, S.; Liu, Y.; Li, H.; Li, G.; Chen, W. Portraying Business District Vibrancy with Mobile Phone Data and Optimal Parameters-Based Geographical Detector Model. *Sustain. Cities Soc.* **2023**, *96*, 104635. [CrossRef]
41. Zhou, S.; Xie, M.; Kwan, M.-P. Ageing in Place and Ageing with Migration in the Transitional Context of Urban China: A Case Study of Ageing Communities in Guangzhou. *Habitat. Int.* **2015**, *49*, 177–186. [CrossRef]

42. Zhang, X.; Gao, F.; Liao, S.; Zhou, F.; Cai, G.; Li, S. Portraying Citizens' Occupations and Assessing Urban Occupation Mixture with Mobile Phone Data: A Novel Spatiotemporal Analytical Framework. *Int. J. Geo Inf.* **2021**, *10*, 392. [CrossRef]
43. Deng, X.; Liu, Y.; Gao, F.; Liao, S.; Zhou, F.; Cai, G. Spatial Distribution and Mechanism of Urban Occupation Mixture in Guangzhou: An Optimized GeoDetector-Based Index to Compare Individual and Interactive Effects. *Int. J. Geo Inf.* **2021**, *10*, 659. [CrossRef]
44. Ravenscroft, N. The Vitality and Viability of Town Centres. *Urban. Stud.* **2000**, *37*, 2533–2549. [CrossRef]
45. Zheng, Z.; Zhou, S.; Deng, X. Exploring Both Home-Based and Work-Based Jobs-Housing Balance by Distance Decay Effect. *J. Transp. Geogr.* **2021**, *93*, 103043. [CrossRef]
46. Zhou, X. Spatial Variation of Self-Containment and Jobs-Housing Balance in Shenzhen Using Cellphone Big Data. *J. Transp. Geogr.* **2018**, *68*, 7. [CrossRef]
47. Tian, L.; Yao, Z.; Fan, C.; Zhou, L. A Systems Approach to Enabling Affordable Housing for Migrants through Upgrading Chengzhongcun: A Case of Xiamen. *Cities* **2020**, *105*, 102186. [CrossRef]
48. Liu, Y.; Li, Z.; Breitung, W. The Social Networks of New-Generation Migrants in China's Urbanized Villages: A Case Study of Guangzhou. *Habitat. Int.* **2012**, *36*, 192–200. [CrossRef]
49. Huang, C.-Y.; Wen, T.-H. Optimal Installation Locations for Automated External Defibrillators in Taipei 7-Eleven Stores: Using GIS and a Genetic Algorithm with a New Stirring Operator. *Comput. Math. Methods Med.* **2014**, *2014*, 241435. [CrossRef]
50. Fotheringham, A.; Brunsdon, C.F.; Charlton, M. *Geographically Weighted Regression: The Analysis of Spatially Varying Relationships*; John Wiley & Sons: Hoboken, NJ, USA, 2003.
51. Gao, F.; Li, S.; Tan, Z.; Zhang, X.; Lai, Z.; Tan, Z. How is Urban Greenness Spatially Associated with Dockless Bike Sharing Usage on Weekdays, Weekends, and Holidays? *ISPRS Int. J. Geo. Inf.* **2021**, *10*, 238. [CrossRef]
52. Deng, X.; Gao, F.; Liao, S.; Li, S. Unraveling the Association between the Built Environment and Air Pollution from a Geospatial Perspective. *J. Clean. Prod.* **2023**, *386*, 135768. [CrossRef]