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AED Inequity among Social Groups in Guangzhou

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Abstract: Automated external defibrillators (AEDs) are regarded as the most important public facility after fire extinguishers due to their importance to out-of-hospital cardiac arrest (OHCA) victims. Previous studies focused on the location optimization of the AED, with little attention to inequity among different social groups. To comprehensively investigate the spatial heterogeneity of the AED inequity, we first collected AED data from a WeChat applet. Then, we used the geographically weighted regression (GWR) model to quantify the inequity level and identify the socio-economic status group that faced the worst inequity in each neighborhood. Results showed that immigrants of all ages suffer a more severe AED inequity than residents after controlling population and road density. Immigrants face more severe inequity in downtown, while residents face more severe inequity in the peripheral and outer suburbs. AED inequity among youngsters tends to be concentrated in the center of each district, while inequity among the elderly tends to be distributed at the edge of each district. This study provides a new perspective for investigating the inequity in public facilities, puts forward scientific suggestions for future AED allocation planning, and emphasizes the importance of the equitable access to AED.

Keywords: AED; inequity; spatial disparities; social groups

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1. Introduction

Out-of-hospital cardiac arrest (OHCA) is a major cause of mortality worldwide [1,2]. According to the China Cardiovascular Health and Disease Report 2019, it was estimated that there are 544,000 OHCA cases in China annually, equivalent to one person dying of cardiac arrest every minute, but less than 1% survive [3]. A 7–10% decrease in survival has been reported for each minute delay in the treatment of the patients with OHCA [4,5]. The early implementation of cardiopulmonary resuscitation (CPR) and defibrillation has been proven in numerous clinical practices to be an effective measure to improve the survival rate [6]. Thanks to technology, the emergence and application of automated external defibrillators (AEDs) offer a glimmer of hope for OHCA patients [7]. The AED is a portable medical device that can diagnose specific arrhythmias and provide electrical countershock automatically, which can be used by non-specialists to save patients in OHCA [8,9]. It was found that performing first aid with AED within 3 to 5 min improved the survival rate to 50 to 70% [10]. Therefore, AEDs are vital to the life safety and health of urban residents, especially in megacities.

However, due to the insufficient numbers or uneven distribution of AEDs, only a minority of the OHCA cases in public places use AED before the ambulance arrives [7,11–13]. Due to the late start of the implementation and popularization of the AED in China, the number and popularization rate of the existing AED is lower than that of the developed countries. Therefore, relevant research mainly focused on AED site selection or location optimization [8,13–17]. In general, these studies suggested that AEDs should be located in high-risk areas and readily accessible by proposing strategies for location optimization, which can be categorized into 3 types: previous OHCA cases-based strategy, population density-based strategy, and land use-based strategy. The first strategy selects AED locations in high-risk areas, which is extracted by geocoding the historical OHCA cases and mapping their density [4,8,13,18]. The second strategy advocates placing more AEDs in areas with higher population density [13,17,19–21]. The third strategy quantifies the risk of OHCA by assigning weights to various land uses according to their human activity intensity [4,8,22]. These existing studies have well provided various strategies for AED placement, but they remained in the site selection stage where AED started from scratch, and the equity of AED distribution was seldom discussed.

As an emergency medical facility, the equity of AED is critical. Equitable AED distribution helps to promote the health and safety of the residents and mitigates the inequality of emergency medical resources [13,15]. Currently, studies have investigated medical facility equity with different socio-economic levels and household registration or different ages of population distribution [23–25]. They demonstrated that medical facilities are more likely to be constrained in socio-economically disadvantaged areas than in more affluent communities because low-income groups often have less access to medical facilities due to geographic remoteness and the low-cost modes of travel [23,26–30]. Firstly, the local financial input tends to favor the communities of high socio-economic status, maintaining adequate local medical resources. Secondly, neighborhoods with rich medical resources and high accessibility have higher land prices keeping disadvantaged groups away [28,30]. However, as a public emergency medical facility, the equity of AED distribution should prioritize those disadvantaged for benefits, such as the elderly and immigrants [29,31,32]. Some cases illustrated that medical facilities are located disproportionally among different social groups, especially vulnerable such as the poor, immigrant, and elderly populations in both developing and developed countries which are related to the ongoing healthcare system development by high-capital investment [24,33]. Increasing the number of multi-level medical facilities has always been the goal of the healthcare system reform; however, equity is often ignored.

Despite the fact that numerous studies have explored the accessibility of medical facilities and their equity [24–26,29,31,32], most of them made great contributions to the overall association between medical facilities and socio-economic status by using regression models, Gini coefficient method, and Mann–Whitney U test and so on [26,28,29,32]. For example, Rong et al., indicated that the supply of healthcare institutions was balanced with the total population by using the Gini index, ignoring the variation in different social groups [28]. Jin et al. found that high-income groups have better access to medical facilities than low-income groups in a study which compared equities in different social groups [23]. Cheng et al. compared the inequitable distribution of the elderly and three types of geriatric medical facilities by using accessibility analysis and the Gini index and found the distribution of nursing homes is more equitable for the elderly, compared to daycare centers and assisted-dining facilities [32].

However, most of the existing studies seldom considered spatial heterogeneity. That is, the distribution of social groups and the medical facility's equity for them are both spatially varying. Theoretically, ignoring the spatial heterogeneity of the AED equity may result in neutralizing the positive (equitable) and negative (inequitable) relationship between the medical facilities and socio-economic status in different spatial locations. In addition, in the process of allocating emergency medical resources such as AED, it is challenging to consider the degree of population agglomeration and equitable distribution at the urban scale, while achieving this goal at the local scale (such as a region) is relatively more practical and instructive. The inequity of the AED needs to be considered on both urban and local scales. The urban scale gives priority to strategic control, and the local scale centers on implementation. Therefore, it is of practical significance to explore the spatial heterogeneity of the correlation between AED distribution and sociodemographic attributes. As a local regression model, geographically weighted regression (GWR) has advantages in unraveling the spatially varying relationship between AED availability and any neighborhood sociodemographic groups, hence quantifying the AED inequity level in each neighborhood on the urban scale [34,35]. In addition, the AED inequity will be comprehensively measured and the social group facing the worst inequity in each neighborhood will be identified based on the spatially varying coefficients of the GWR model, which yields helpful insights for AED planning and optimization and the mitigation of the AED inequity.

To address the existing limitations above, the GWR model was adopted to explore the association between AED and social groups in each neighborhood in Guangzhou, China. The purpose of this study is twofold: (1) How is the spatial pattern of AED inequity among different social groups? And (2) which groups are undergoing the worst AED inequity?

2. Materials and Methods

2.1. Theoretical Framework

The research object of this study is equity. The correlation between the proportion of various social groups and the availability of the AED in each neighborhood is essential to measuring equity. Figure 1. defines the inequity [35]. The negative correlation indicates the inequity for this social group [35,36]. For instance, the proportion of the elderly immigrants is negatively associated with the available AED, indicating that the elderly immigrants in this neighborhood are unlikely to be covered by more AEDs than the locals.

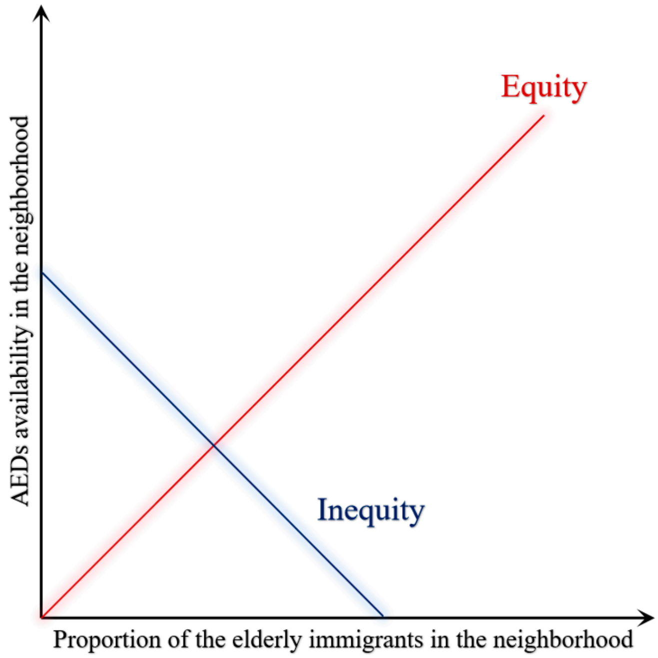

Figure 1. Definition of AED inequity.

Figure 2 displays the theoretical framework of this study. Due to data availability, we take into account the population diversification in terms of age and household registration status. Hence, the social groups included in this study are divided into six categories: young residents, middle-aged residents, elderly residents, young immigrants, middle-aged immigrants, and elderly immigrants. The relationship between neighborhood AED and social groups is established. Given the spatial non-stationarity, the distribution of the AED inequity is examined in multi-social groups. The inequity level and the group facing the worst AED inequity are ascertained by comprehensively measuring the AED inequity across neighborhoods and social groups.

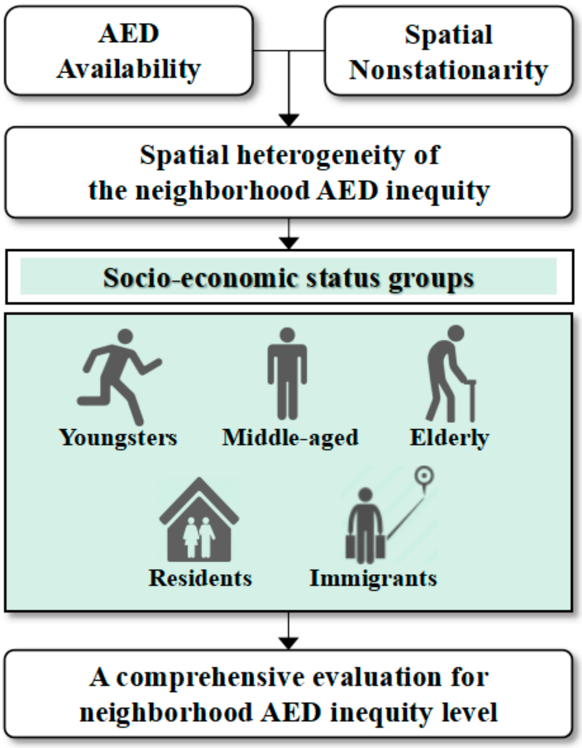

Figure 2. The theoretical framework of the AED inequity.

2.2. Study Area

Guangzhou, China, is a megacity in southern China with a population of more than 18 million [35,37]. This study chooses nine districts of Guangzhou as the study area with 2055 neighborhoods and an area of about 3600 km^2 [38]. The analytics spatial unit is the neighborhood, which is the census unit at the grass-roots level in China. The downtown of Guangzhou comprises the first four districts [39,40]. At present, the total number of AEDs in public has exceeded 1100, among which 16 metro lines and 302 stations have been realizing a complete coverage by AED. In 2021, the Guangzhou Municipal Government promulgated the Work Plan for the Allocation of AEDs in Public Places of Guangzhou (Draft for Comment) [41], planning to fully cover the city's landmark transportation hubs and scenic spots, large sports venues, street offices, community health service centers, and other crowded places by 2025, and to install 4500 AEDs by 2035 (30 per 100,000 population). However, the population structure of Guangzhou is complex, accommodating a large number of vulnerable groups, including the elderly and migrant workers [35]. Therefore, it is very necessary to analyze the equity of emergency medical facilities for various vulnerable groups in Guangzhou.

2.3. AED Data

The AED data in this study were obtained from a WeChat applet named Lifesaving Map via a Python script [42] (Figure 3a). After collecting the text address of the AEDs from an applet, the geo-locations (coordinates) of the AEDs were obtained by using Baidu Map geocoding API. Through manual inspection by overlay geocoding results with online maps, the correct geo-locations of 1006 AEDs were finally obtained and the geocoding hit rate reached 91.5%, which is of high accuracy and can be used for subsequent research.

The measurement of AED availability is shown in Figure 3b. Firstly, the effective rescue time of OHCA patients is between 3 and 5 min [43]. Second, it takes about 1.5 min to set up an AED before use [44], which means only 3.5 min is left for AED delivery. Third, the average running speed is 8 km/h (133 m/min), and the maximum travel distance in which an OHCA eyewitness can successfully deliver an AED (round trip) is about 230 m [15,45]. Therefore, we first generated a point density raster layer with a search radius of 230 m and then calculated the mean of the density raster value of each neighborhood as the AED availability.

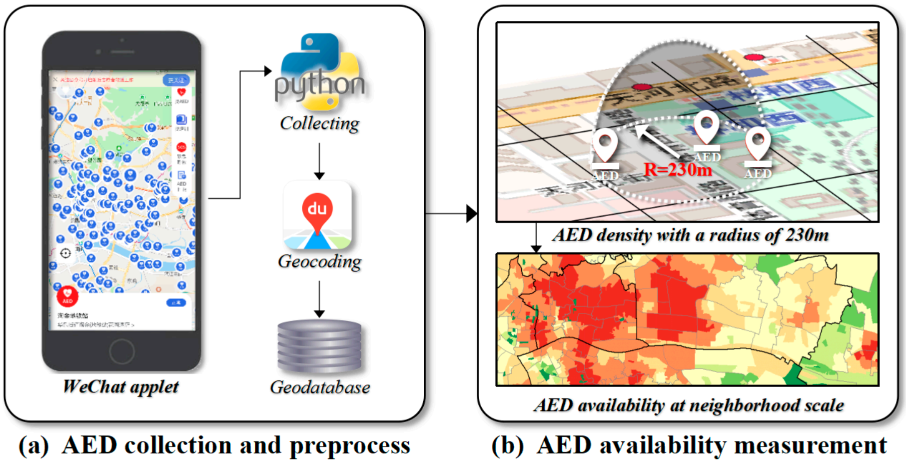

Figure 3. The process of the data collection and availability measurement of the AED.

2.4. Demographic Data

The demographic data at the neighborhood census scale were obtained from the Seventh National Census data. In the current study area, the predominant demographic characteristics were notably marked by high rates of aging and a substantial proportion of immigrants [35,46–48]. Hence, a delineation into three age brackets was conducted, based on the differentiation between the residents and immigrants: the young (ages 19–45), the middle-aged (ages 46–60), and the elderly (over 60 years of age). Specifically, within the study region, the populations of the young residents, young immigrants, middle-aged residents, middle-aged immigrants, elderly residents, and elderly immigrants were quantified at 9.656 million, 6.929 million, 3.358 million, 1.904 million, 1.858 million, and 0.564 million, respectively (Figure 4, Table 1). Given the uneven distribution of the urbanization level and population density in Guangzhou [49], the density of the population and road network were taken as control variables in addition to the above six social group variables.

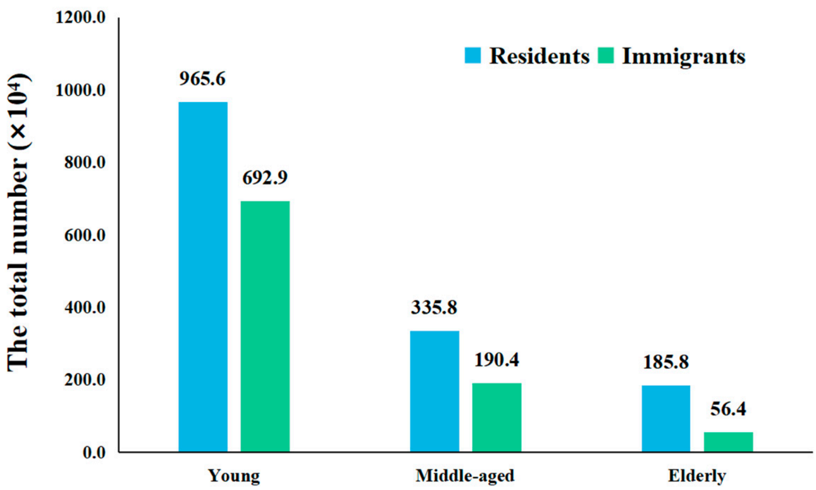

Figure 4. The number of the six social groups in the study area.

First, Pearson's correlation was applied to test potential multicollinearity. If the absolute value of Pearson's coefficient exceeded 0.7, only one of the two variables was retained. Second, the selected variables were standardized so that the mean was 0 and the standard deviation was 1 to identify the most essential determinant [35,36]. The correlation coefficient between MR and ER reached 0.831, which is greater than 0.7. Previous studies have shown that OHCA occurs mainly in the elderly [17,50,51]. Therefore, ER was retained in the model. Finally, the model included YR, ER, YI, MI, and EI as the predictor variables, and POP and RD as control variables.

Table 1. Summary statistics of the variables.

Categories	Variables	Explanation	Mean	SD
Social groups	Young residents (YR)	Proportion of residents aged 19–45 (%)	31.57	0.05
	Middle-aged residents (MR)	Proportion of residents aged 46–60 (%)	14.37	0.04
	Elderly residents (ER)	Proportion of residents aged above 60 (%)	10.25	0.06
	Young immigrants (YI)	Proportion of immigrants aged 19–45 (%)	18.46	0.09
	Middle-aged immigrants (MI)	Proportion of immigrants aged 46–60 (%)	6.31	0.03
	Elderly immigrants (EI)	Proportion of immigrants aged above 60 (%)	2.34	0.02
Control variables	Population density (POP)	Population density (person/km^2)	27,512.36	29,854.67
	Road density (RD)	Road density (km/ km^2)	6.72	7.03

2.5. Geographically Weighted Regression

First, OLS regression was used to model the global association between AED availability and social groups. Multicollinearity was measured by a variance inflation factor (VIF). Jarque–Bera test was used to check the normal distribution of the residual, which determines if the application of the GWR was necessary [52].

However, the OLS regression model is a global model, and its estimated coefficients are constant rather than spatially heterogeneous, ignoring the model coefficients and fitting differences of different geographical units [53]. The GWR model is a regression model considering spatial autocorrelation [54]. Because GWR incorporates spatial variability into the coefficient estimation, it has a better fitting performance in the regression results [55]. To comprehensively quantify the spatially varying association between AED availability and social groups, the inequity was modeled by applying GWR, which can be expressed as follows.

$$y_i = \beta_0(u_i, v_i) + \sum_k \beta_k(u_i, v_i) X_{ik} + \varepsilon_i \quad (1)$$

where y_i is the response variable at neighborhood i; $\beta_0(u_i, v_i)$ is the intercept at position i; $\beta_k(u_i, v_i)$ is the coefficient (weight) of the kth predictor variable estimated for each neighborhood i at location (u_i, v_i); ε_i is a random error. Weights were generated based on bandwidth, which is related to kernel type, bandwidth method, distance, and the number of adjacent points. Using a fixed kernel type, the corrected Akaike Information Criterion (AICc) was applied to calculate the optimal bandwidth. AICc is an indicator to compare the OLS and GWR in terms of the model performance and fitting. When the difference of AICc between models exceeds 3, the lower AICc and higher R-square indicate better goodness of fit [34,54].

To measure the type and level of the AED inequity considering spatial heterogeneity, we further extended the results of the GWR model by overlaying and summarizing the GWR coefficients of the social group variables. The neighborhood where the GWR coefficient of each variable is significantly negative is coded as 1, and the remaining neighborhood is coded as 0 [36]. According to previous studies, the level of inequity is categorized into four types: low (0–1), moderate (1–2), high (2–3), and extreme (3–5) [35]. Moreover, the neighborhood-scale map of the social group facing the worst inequity is visualized based on the standardized negative coefficient of the social groups [35,36].

3. Results

3.1. Spatial Distribution of AED Availability

Figure 5 displays the neighborhood AED availability. High availability areas are concentrated in the downtown, including Yuexiu, western Tianhe, eastern Liwan, northern Haizhu district, and southern Baiyun. In general, the spatial distribution of the AED availability is highly consistent with the pattern of the urban population and economic distribution.

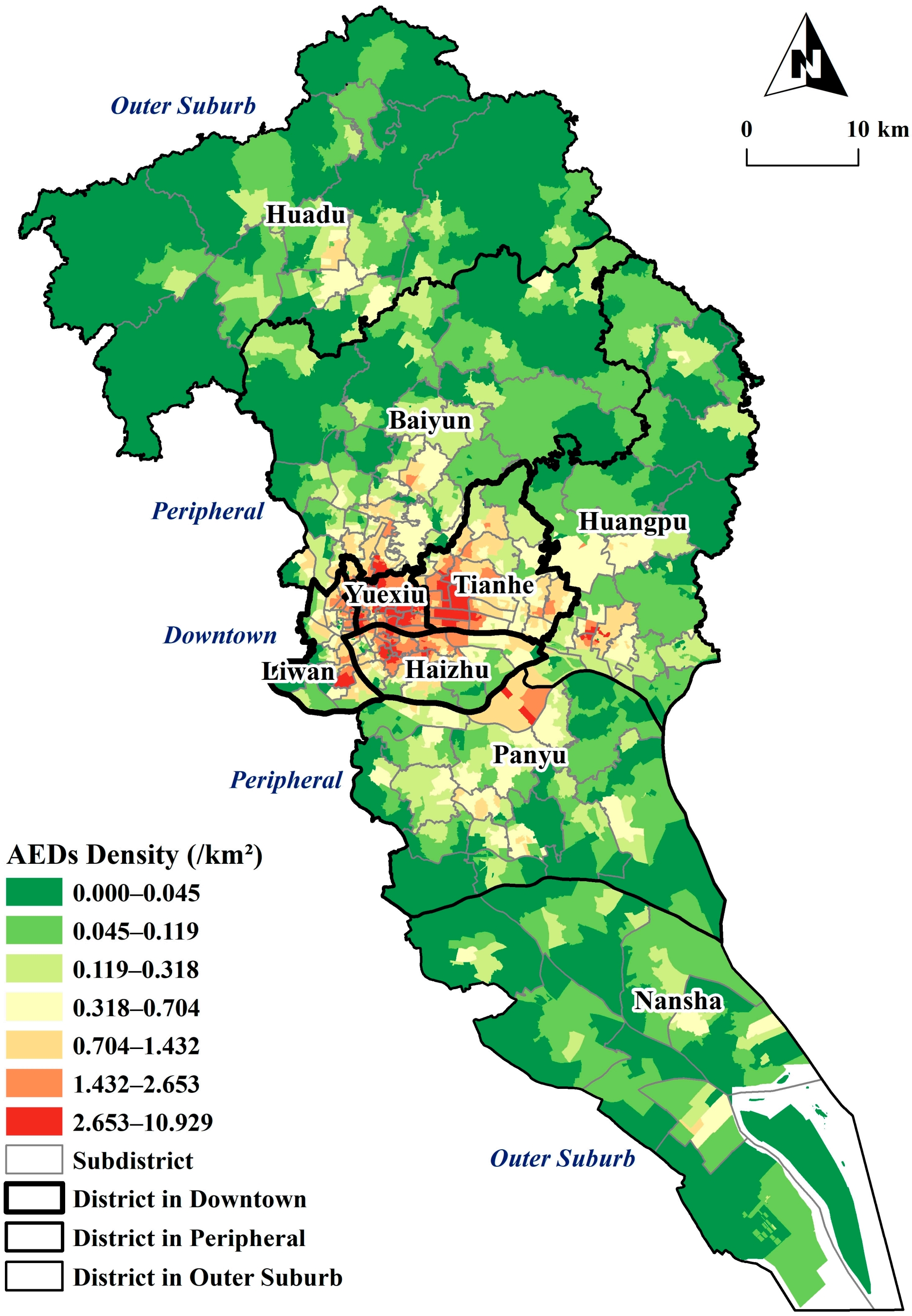

Figure 5. Spatial distribution of AED availability.

3.2. Global AED Inequity

The AED availability was significantly and negatively associated with YR and MI, while ER, YI, EI, POP, and RD were the opposite (Table 2). It indicates that young residents and middle-aged immigrants are suffering AED inequity, while elderly residents, young immigrants, and elderly immigrants tend to be covered by more AEDs on a city-wide level. Among the five social groups, the maximum absolute value of the negative coefficient is 0.303 of MI, which indicates that middle-aged immigrants are the groups facing the worst AED inequity. The high residual autocorrelation was found in the Jarque–Bera statistics and spatial autocorrelation analysis, so a local GWR analysis is necessary.

Table 2. Results of OLS regression model.

Categories	Variables	Coefficient	Robust SE	Robust t	Robust P	VIF
	Intercept	0.979	0.030	32.441	0.000	-
Social groups	YR	−0.122	0.028	−4.369	0.000	1.807
	ER	0.689	0.054	12.832	0.000	2.304
	YI	0.519	0.054	9.572	0.000	2.175
	MI	−0.303	0.033	−9.177	0.000	1.494
	EI	0.205	0.083	2.481	0.013	1.311
Control variables	POP	0.674	0.002	10.689	0.000	1.407
	RD	0.536	0.003	9.974	0.000	1.032
Model diagnostics	R^2: 0.336, adjusted R^2: 0.324, AICc: −3752.491, Koenker (BP): 178.213 **, Jarque–Bera: 402.121 **					

SE = standard error; VIF = variance inflation factor. ** Significant at the 0.01 level.

3.3. Local AED Inequity

Table 3 presents the GWR model results, which quantify the local relationship between the AED availability inequity and the social groups in the neighborhood. Compared with OLS, the lower AICc and higher R-square of the GWR model indicate that GWR was more effective in quantifying the local relationship between the AED availability inequity and social groups. The mean GWR coefficients of YI are the lowest (−0.434), followed by EI (−0.14) and MI (−0.077), indicating that the immigrants of all ages are suffering from a more severe AED inequity than the residents. In addition, the spatial patterns of the AED inequity of the social groups are shown in Figure 6.

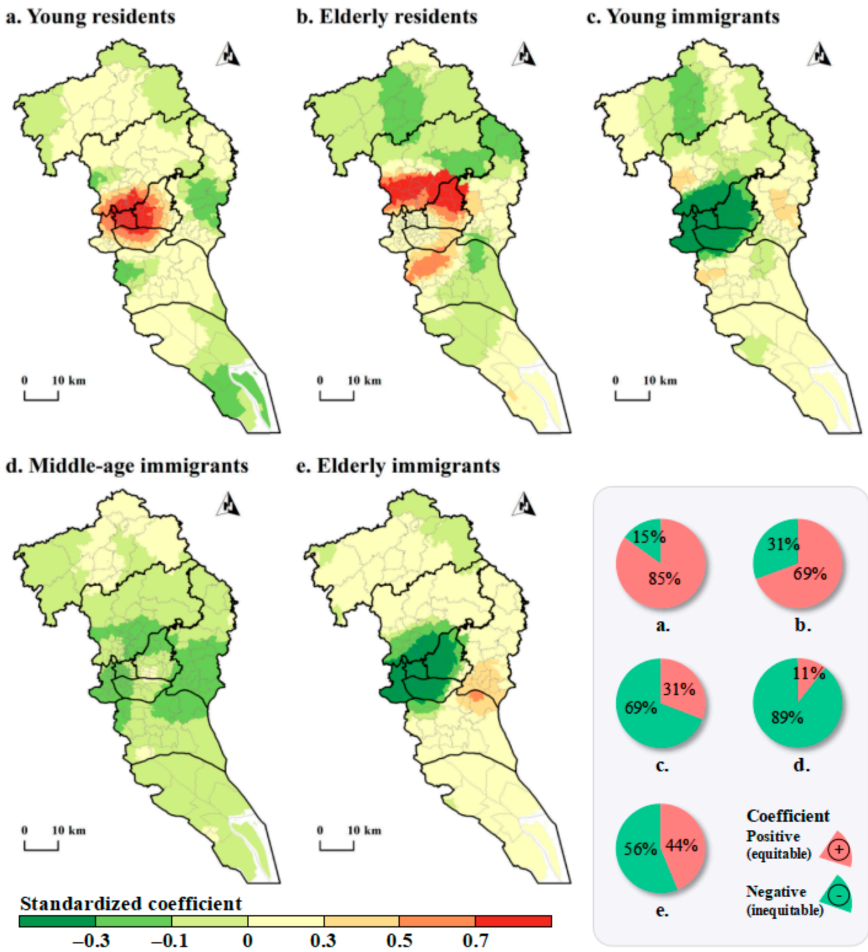

Figure 6. Spatial distribution of the GWR coefficients.

Table 3. Results of GWR regression model.

Categories	Variables	Min	Max	Mean	SD
	Intercept	−0.011	2.511	1.253	0.031
Social groups	YR	−0.279	0.919	0.329	0.067
	ER	−0.196	1.147	0.186	0.290
	YI	−1.294	0.497	−0.434	0.108
	MI	−0.211	0.046	−0.077	0.060
	EI	−0.568	0.520	−0.140	0.054
Control variables	POP	0.105	0.684	0.489	0.347
	RD	0.078	0.541	0.414	0.607
Model diagnostics	R^2: 0.724, adjusted R^2: 0.702, AICc: −3856.174, bandwidth: 24,247.853				

3.3.1. Young Residents

In terms of young residents, the result of the global OLS regression model hints that the proportion of young residents is negatively associated with the neighborhood AED availability (Table 2). However, the local GWR regression model reports that inequity is observed in only 15% of the neighborhoods with the mean GWR coefficients of 0.329, especially in southern Nansha, middle Huangpu, western Panyu, and Huadu districts (Figure 6a). Equity is observed in the downtown, including Yuexiu and western Tianhe district.

3.3.2. Elderly Residents

The global OLS model reports that elderly residents are significantly positively correlated with the neighborhood AED availability with the highest standardized coefficient of 0.689 (Table 2). Moreover, the local GWR model finds more details that the AED equity for elderly residents is observed in 69% of the neighborhoods with the mean GWR coefficients of 0.186, especially in southern Baiyun, northern Tianhe, and north-western Panyu district (Figure 6b). The AED inequity for elderly residents is distributed in northern (including Huadu, northern Baiyun, and northern Huangpu district) and southern Guangzhou (including eastern Panyu and northern Nansha district).

3.3.3. Young Immigrants

Regarding young immigrants, 69% of the neighborhoods are observed with AED inequity with the lowest mean GWR coefficients of −0.434 (Table 3). On the contrary to young residents, the downtown including Yuexiu and western Tianhe district is the area that suffers from the most severe AED inequity for young immigrants, while equity is observed in the peripheral and outer suburbs including southern Huangpu, southern Nansha, western Baiyun, north-western Haizhu district (Figure 6c).

3.3.4. Middle-Aged Immigrants

Both the OLS and GWR models report a significant negative relationship between middle-aged immigrants and AED availability (Table 2). Compared with OLS, GWR results provide more details on the spatial heterogeneity of the AED inequity. The middle-aged immigrants are the group with the largest number of 89% neighborhoods with significant AED inequity, especially in peripheral areas including southern Huangpu, northern Panyu, the middle of Baiyun, and Liwan district (Figure 6d).

3.3.5. Elderly Immigrants

Like young immigrants, downtown is the area with severe inequity for elderly immigrants, especially at the junction of Tianhe, Yuexiu, and Haizhu districts. In contrast, the peripheral and outer suburbs such as eastern Guangzhou including southern Huangpu and northern Panyu district are observed with relative equity. Among the five groups of the population, elderly immigrants are the group with the most balanced number of equitable (44%) and inequitable (56%) neighborhoods.

3.4. Spatial Patterns of AED Inequity Level

Figure 7 displays the spatial distribution of the comprehensive AED inequity level. A high level of AED inequity is mainly distributed in the northern half of Guangzhou, including all over the four districts of downtown, and half of Baiyun and Huadu districts, where most of the neighborhoods suffer from high AED inequity. In addition, a small number of neighborhoods facing extremely high inequity are located in the outer suburbs including the marginal areas of Huadu and Baiyun district. On the contrary, low and moderate levels of comprehensive AED inequity are observed in southern and eastern Guangzhou including most of the Huangpu, Panyu, and Nansha districts.

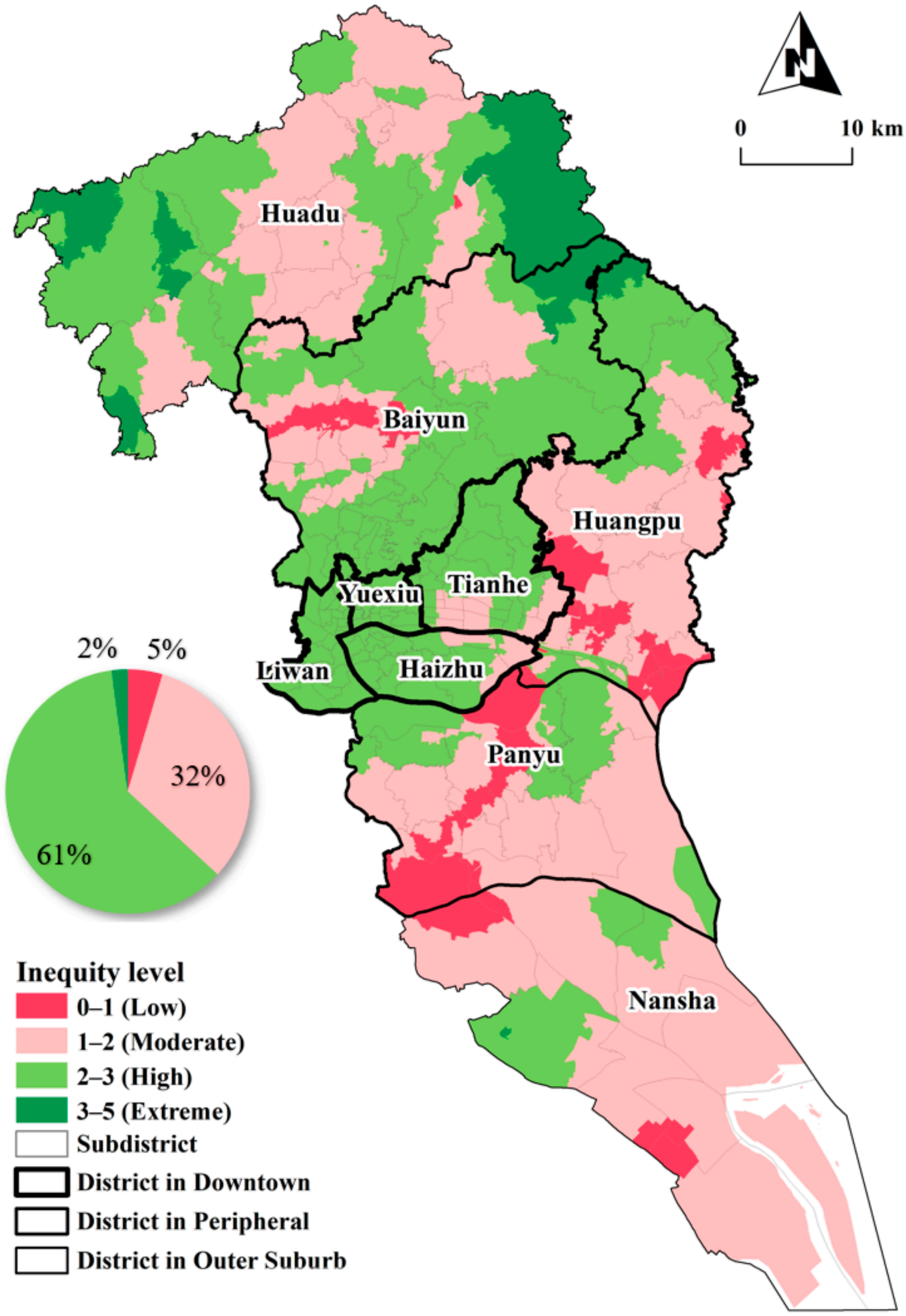

Figure 7. Spatial distribution of AED inequity.

Figure 8 presents the supply map of the social groups facing the worst AED inequity, which is conducive to identifying the AED inequity differences faced by the social groups within each neighborhood. The distribution of the group facing the worst AED inequity is spatially heterogeneous. The downtown including four districts is the area where the immigrants are facing more severe AED inequity than the residents, while the AED inequity of the residents is observed in the peripheral and outer suburbs oppositely. Regardless of being residents or immigrants, the AED inequity among youngsters tends to be concentrated in the center of each district, while the AED inequity among the elderly is distributed in the fringe of each district.

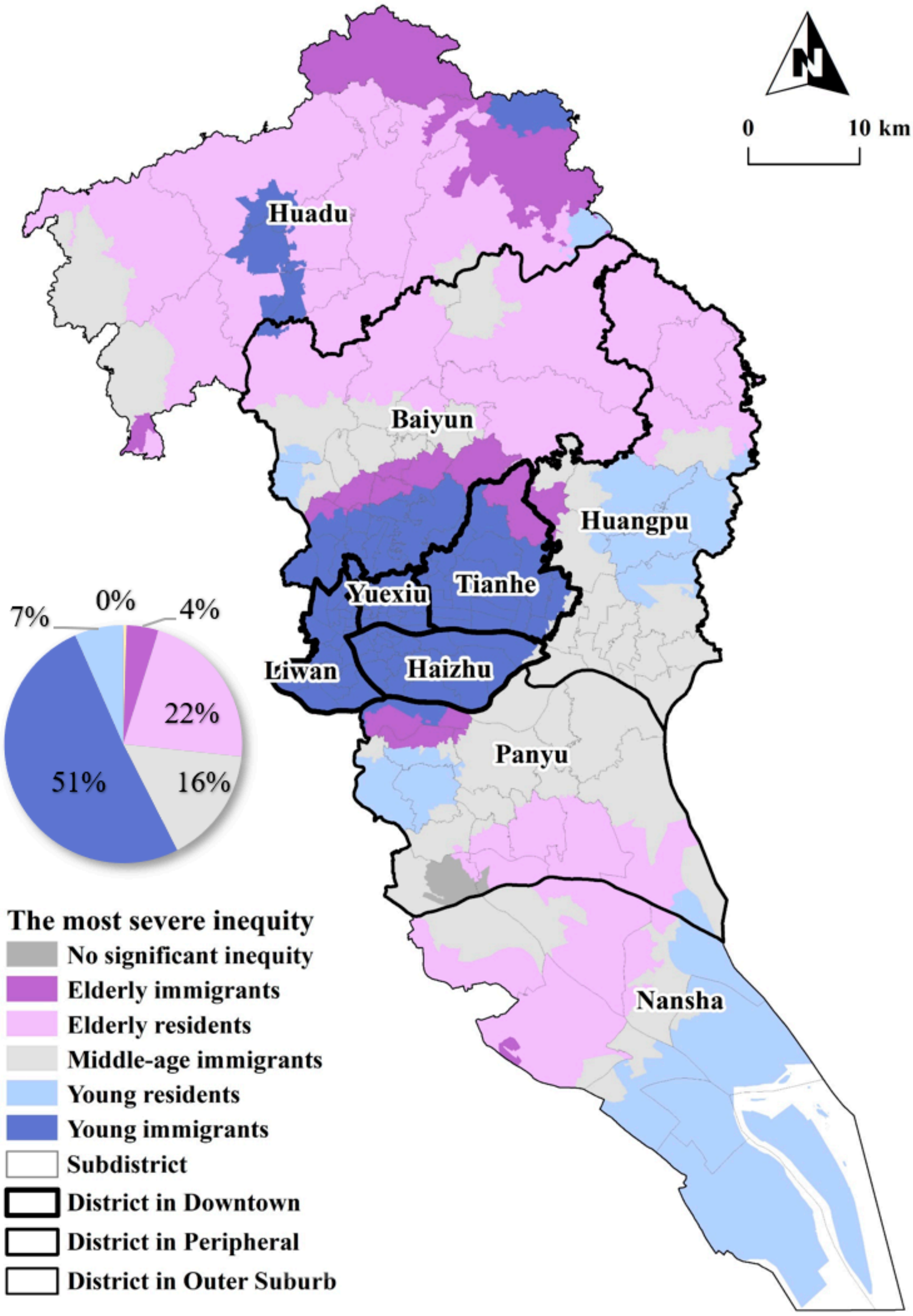

Figure 8. Spatial distribution of the worst type of AED inequity in each neighborhood.

Figure 9 compares the equity of various social groups in each type of neighborhood in Figure 8. Although Figure 8 identifies the social groups facing the most unfair access to AEDs in each neighborhood, it can be observed from Figure 9 that the equity degree of the different social groups in each neighborhood was significantly different. It is worth noting that groups of the same age but different categories in each type of neighborhood in Figure 8 exhibited opposite characteristics. For example, in the Yi-inequity neighborhood, which accounted for 51% of the study area, the YI group had the most severe degree of inequality, with the lowest average standardization coefficient of −0.889. On the contrary, the YR group in this kind of neighborhood had the highest degree of equity, and its average standardized coefficient was the highest, reaching 0.627. Similar patterns had been observed in other types of neighborhoods. This phenomenon reflects the inequity of access to AED facilities among residents and immigrants of the same age group. The relevant reason may be the mismatch between the residence of the various groups and the distribution of AED facilities, which still needs further investigation in future work.

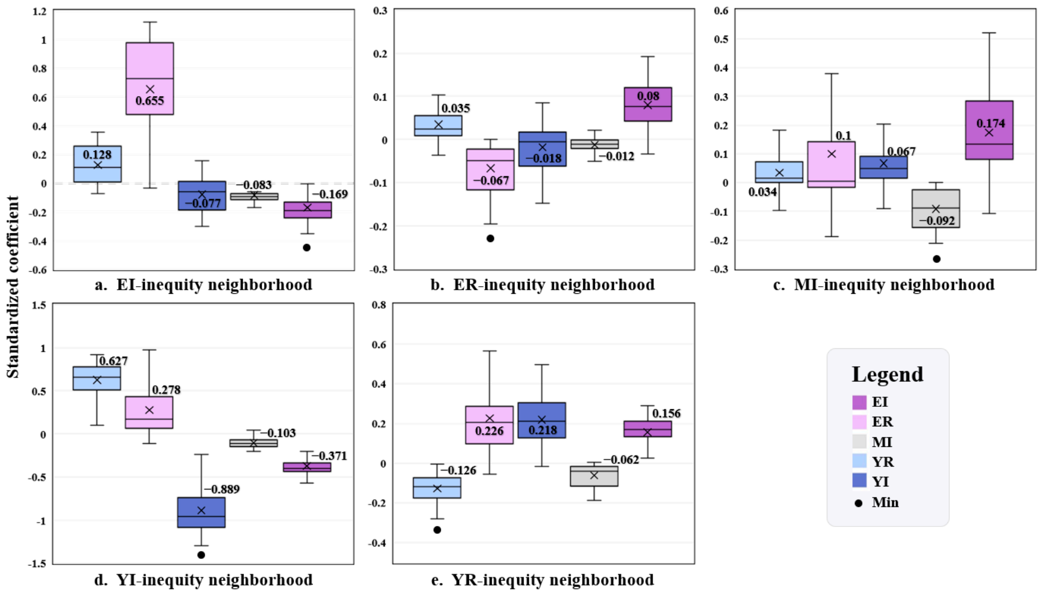

Figure 9. Standardized coefficient statistics for each type of neighborhood.

4. Discussion

4.1. Inequitable Access to AED in Guangzhou

Severe local AED inequity is mainly observed among immigrants including youngsters, middle-aged, and the elderly. From a macro point of view, the spatial distribution of AED equity faced by the five groups of the social groups is significantly heterogeneous. In general, the neighborhoods where immigrants suffer from inequity are concentrated in four districts of downtown and southern Baiyun district. On the contrary, the AED inequity of the residents is mainly distributed in the peripheral and outer suburban neighborhoods. Whether immigrants or residents, the youngsters faced with AED inequity mostly live in the center of Guangzhou or each district, while the AED inequity among the elderly is mostly distributed on the outskirts of downtown and in the outer boroughs of the city. It indicates that the supply and demand relationship between the AED facilities and the social groups is imbalanced. Through the comprehensive evaluation of the AED inequity, it is suggested that policymakers and urban planners should be attentive to the equity between the social groups in the neighborhoods, rather than just the total population when allocating such emergency medical facility resources.

The high aging population is one of the demographic features in Guangzhou [48]. Regarding age, OHCA is most common in the elderly because of the higher rates of cardiovascular disease, compared with the young and middle-aged [17,50,51]. Previous studies have found that the elderly are often at a disadvantage in terms of the access to medical care [32,56,57]. As an emergency medical facility, AED inequity for the elderly is observed in 26% of the neighborhoods, especially in the peripheral and outer suburbs of Guangzhou, which is consistent with previous studies on healthcare inequity. The elderly are the disadvantaged group with particular demands for AED due to their physical condition. The local inequity of the AED availability across the two elderly groups is identified and located by the GWR model, which should be mitigated in future AED allocating.

Excessive immigration is another demographic feature that Guangzhou attracts a large number of young migrant workers every year [47]. Although OHCA rates are lower in younger people, the number of young people is more than six times that of the elderly, especially young immigrants. Existing studies have reported that due to the institutionalized discrimination caused by the Hukou system, immigrants are often excluded from local benefits, including public services and healthcare [58,59]. In this study, AED inequity for young immigrants is observed in 51% of the neighborhoods, especially downtown. Urban villages in downtown are often regarded as immigrant-receiving neighborhoods, because most immigrants live in urban villages in the inner fringe of downtown or the urban and rural fringe of the city, and the number of immigrants living in these places far exceeds the number of residents [60].

On the one hand, due to the lack of economic development and the low socio-economic level of such low-cost neighborhoods, the government's financial investment is usually relatively small, resulting in the inadequate allocation of the public service facilities in various aspects [24,33], including medical facilities such as AED. In addition, most low-cost neighborhoods represented by urban villages and old communities have few public places suitable for AED placement due to disrepair or single functions of buildings and land [61]. On the other hand, current AED facility planning is usually configured according to the population in each neighborhood [15]. However, due to large numbers and high mobility, and the fact that some migrants are not registered, the population statistics are inaccurate but take too long to update. Therefore, it is difficult to allocate a sufficient number of AEDs to residents and immigrants in each neighborhood. In addition to population and land characteristics, low-cost neighborhoods with immigrant concentrations, typically have lower levels of education and income, which may indirectly affect the risk of OHCA in public [15]. Bystanders with lower income and education levels usually have insufficient medical common knowledge and rescue skills, which makes it difficult for them to provide effective first aid to victims and promotes the survivor rate [62,63]. In conclusion, the demographics and geographical location of the neighborhood can influence the inequity in the availability of AED facilities.

4.2. Implications for AED Facility Management and Optimization

The results of this study provide new insights and implications for AED configuration strategies. First, although the current AED facility planning takes into account the local population density, most of them ignore the characteristics of the population structure and socio-economic level, which have significant spatial heterogeneity in the high-density megacity of Guangzhou. As an emergency medical facility for the whole people, the government should intervene in the equity distribution of AED facilities to improve the coverage of the vulnerable groups in the neighborhoods with sufficient AED facilities, instead of focusing on the overall population and continuing to ignore vulnerable groups. This study urges the equity of AEDs as a goal to achieve social equity and basic public service planning. Second, this study provides a technical framework for evaluating the spatial heterogeneity of the inequity in AED facilities, which can provide a comprehensive demographic analysis and visualization of the supply map for AED facility allocation planning and provide a scientific reference for equitable distribution of medical facilities. It should be noted that there are disparities in AED equity among neighborhoods and that neighborhoods with more AED facilities are not necessarily equitable. Therefore, it is necessary to consider the balance between the supply and demand of AED facilities and the spatial disparities of the socio-economic groups, especially in areas with high concentrations of disadvantaged groups. The government should intervene in the redistribution of AED facilities in severely inequitable neighborhoods to ensure vertical equity, giving priority to the interests of the vulnerable groups. Third, the newly released AED resources should be further supplemented to the vulnerable group-gathering neighborhoods, and the local population density, mobility, and structure should be considered. For example, to supplement AEDs in urban villages, 24 h security duty rooms and the largest local wet market can be considered. Finally, it is suggested that the government build an "Internet + First Aid" system, construct an AED network and system, conduct unified management of AED network information, and use information technology to draw an AED public online map. For example, the AED data applied in this study came from the WeChat applet named "AED Lifesaving Map". However, this very powerful applet lacks publicity, which is likely to lead to low usage. Therefore, it is necessary for the government to increase the exposure of this emergency information on social media through online and offline channels.

4.3. Theoretical Implications

Theoretically, the main findings and contributions of this study are to emphasize that the integrated application of the consolidated geospatial modeling technology to other fields will bring new added value. For example, this study applied it to the management and optimization of urban public medical facilities to investigate the equity problem in the distribution of AED facilities. Compared with traditional non-geospatial methods, such as the Gini coefficient and Lorenz curve, the spatial heterogeneity of equity was observed in this study. First, the AED data are obtained through the WeChat applet and Python script, and its neighborhood availability is measured considering the effective rescue time of OHCA and average running speed. Second, given the unique characteristics of population structure in Guangzhou where population aging and mass migration coexist, we focus on the AED inequity instead of the inequality from the perspective of spatial and socio-economic heterogeneity. Third, we investigate the spatially varying AED inequity by the GWR model and identify the severe AED deprivation neighborhoods. The socio-economic status and AED availability of each neighborhood differ greatly. That is, the inequity or equity is only observed in specific neighborhoods, and the global modeling of the whole city will lead to overgeneralization. In this study, AED inequity is comprehensively analyzed for multiple social groups from a micro perspective. The framework of inequity identification using the local regression model in this study can be applied to other social equity issues.

4.4. Limitations

Despite the advantages, there are limitations to be addressed in the future.

- Although this study examines inequity in AED facilities from the perspective of spatial heterogeneity, it could not cover the analysis of the whole social group due to the availability of data, such as for groups with different housing sizes.
- The neighborhood administrative boundary is taken as the spatial unit in this study, and the analysis modeling results may be affected by the modifiable areal unit problem [64].
- Due to data availability, our analysis does not cover the historical OHCA cases. Future studies should obtain more comprehensive variables, AED facility data of more cities, and modeling to consider scale effects.
- This study measured the AED availability based on the maximum rescue time. Further investigation should incorporate both minimum and maximum rescue time ranges for comprehensive understanding.
- Since the collinearity problem needs to be solved before the linear regression model is adopted, one kind of social group was omitted from the model result. In the next step, we will consider other models to avoid this limitation, because inequity is equally important for each social group.

- Although this study identified spatial heterogeneity in the inequality of access to AEDs across social groups, the next step should be to explore the relationship between the equity of various social groups in each neighborhood.

5. Conclusions

The major contribution of this study is to adopt geospatial modeling technology to solve the equity problem in the distribution of medical facilities. The GWR reveals the spatially varying associations between AED and different social groups. Model results show that immigrants of all ages suffer from more severe AED inequity than residents, after controlling the population density and road density. The most significant result of this study, the AED inequity supply map, shows that the distribution of the groups that faced the worst AED inequity has significant spatial heterogeneity. The immigrants downtown face more severe AED inequity than the residents. Conversely, the residents face more severe inequity in peripheral and outer suburbs. Whether resident or immigrant, the AED inequity among youngsters tends to be concentrated in the center of each district, while the AED inequity among the elderly tends to be distributed at the edge of each district. These spatial characteristics of AED supply and demand relations should be emphasized in future AED planning.

The highly aging population and the large number of immigrants are the unique demographic characteristics of Guangzhou. Therefore, when planning and allocating basic medical emergency facilities such as AED, it is particularly important to consider the differences in the population structure and socio-economic status. AEDs are regarded as the most important public facilities after fire extinguishers due to their importance to the lives of citizens. Therefore, for AED planning, it is equally important to improve the number of per capita ownership and promote local equity. This study provides a new perspective for investigating the inequity in public service facilities and emergency medical facilities, puts forward scientific suggestions for future AED distribution planning, and emphasizes the importance of social equity.

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