Access and Equity Assessment Based on Improved Ga2SFCA Method Under Multiple Transportation Modes

A Case Study of the Central City of Changsha, China

Xuehan Yu(✉)

Geography and Resource Management, Chinese University of Hong Kong, Ma Liu Shui, Hong Kong
Yxh721202123@163.com

Abstract. In order to scientifically assess the accessibility and equity of urban residents' access to medical care, a time-cost-based accessibility analysis of three classes of medical service facilities was conducted using a Improved Ga2SFCA Method based on four modes of travel for medical care. The results show that the accessibility of the integrated medical service facilities in Changsha city center varies greatly among the four modes of transportation, except for the double-centered pattern in the private car mode of transportation, and the single-centered pattern in all other modes. The degree of variation in the equity of access to healthcare resources by class is more pronounced than the variation in the equity of access by transportation mode. The difference in the comprehensive accessibility of secondary medical service facilities by multiple transportation modes is significantly smaller than that of primary and tertiary medical service facilities, showing a more equitable spatial distribution pattern. Therefore, in the future, on the basis of improving the infrastructure of transportation network, the central city of Changsha should pay more attention to the balance of medical resources allocation of each level.

Keywords: Accessibility · equity · multi-modal transportation · medical services facilities

1 Introduction

The outbreak and persistence of the Covid-19 novel coronavirus pneumonia epidemic has deepened thinking about the construction of healthy cities [1], of which healthcare services are a key element to be considered [2]. The spatial allocation of medical resources and their accessibility level have a decisive impact on the convenience of medical care for urban residents, while the accessibility directly affects the timeliness and comfort of medical care for residents. However, under the rapid urbanization process, the accessibility of medical treatment differs among different transportation modes [3]. Accurate analysis of the accessibility and equity of multi-level medical facilities under

N. Akhtar et al. (Eds.): PMIS 2023, AHIS 8, pp. 353–364, 2023.
https://doi.org/10.2991/978-94-6463-200-2_37

multiple transportation modes can provide a reference for rational optimization of the spatial layout of urban medical facilities and provide a basis for decision making to promote the equity of urban transportation for medical treatment.

In the study of spatial accessibility of medical facilities, the measurement methods include gravity model, supply-demand ratio model, and two-step movement search method [4]. Currently, the two-step moving search method has become the main research method for measuring the accessibility of medical facilities [5]. Among them, Luo (2003) et al. optimized the 2SFCA model (2000) [6] proposed by Radke et al. to evaluate the accessibility of medical facilities in Chicago [7]. In the assessment of transportation equity of healthcare facilities, existing studies mostly use the spatial distribution balance from the perspective of accessibility to represent its equity, and the evaluation methods mainly include Lorenz curve, locational entropy and Gini coefficient. However, they tend to focus on a single mode of transportation [8], and seldom compare the equity of access to medical care under multiple modes of transportation, and seldom consider the differences of accessibility and equity of medical service facilities of different levels. Therefore, this paper evaluates the accessibility and equity of medical care facilities in the central city of Changsha based on multiple modes of transportation (private car, bus, subway, and walking) and uses the improved two-step search and move method to provide a reference for relevant authorities to promote the equity of medical care transportation.

2 Overview of the Study Area and Data Sources

The study area of this paper is the central city of Changsha, including Furong District, Tianxin District, Yuelu District, Kaifu District, Yuhua District, Wangcheng District and Changsha County, with 119 streets in the study area, a total area of 3915 km^2 and a total population of 4.59 million.

The basic data include administrative areas, road networks, demographics and hospital data in the central city of Changsha (Table 1). In order to analyze and evaluate the accessibility of Changsha central urban area, firstly, the plenum points were extracted for each street, and the plenum points were used to represent the streets, and the population plenum characterized the spatial distribution of the street population.

As of July 2022, Changsha central urban area has 219 metro stations, 7 metro lines, 15,811 stations of general bus lines, and 120 all bus lines. The car and pedestrian road traffic data in the central urban area of Changsha City revised and cleaned, based on the relevant road norms and urban characteristics of the road reclassification, a total of five categories, with reference to the normative design speed assignment operation (Table 2).

As of July 2020, Changsha central urban area has 28 tertiary hospitals, 230 general and specialist hospitals, 343 health centers and community health service stations (Fig. 1), and the bed count data are mainly from the 99 hospital library (http://yyk.99.com.cn/changsha/) and the official website of each hospital, and for the missing institutional data, according to the 2020 The average number of beds in various types of health institutions calculated from the Changsha Statistical Yearbook in 2020 was substituted.

Table 1. Data types and sources

Type	Highway	Expressway	Urban main road	Urban secondary road	Urban feeder road
Speed	110 km/h	80 km/h	60 km/h	45 km/h	30 km/h
Pedestrain	--	90 m/min	90 m/min	90 m/min	90 m/min

Table 2. Traffic network data conversion and assignment

Data type	Representative Metrics	Data source
Administrative district data	Administrative district (Street)	DataV.GeoAtlas
	Administrative district (district)	
Road network data	Automobile & pedestrian traffic road network	http://www.openstreetmap.com
	Bus line	Gaode map open platform
	Subway line	
	Bus stops	
	Subway station	
Demographic data	Medical resource POI data	Gaode map open platform

3 Research Methodology

The advantage of improved Ga2SFCA method is that two moving searches are performed from the supply and demand perspectives, taking into account the interactions between the two. Also considering the distance attenuation factor, many scholars have improved the traditional two-step moving search method, in which the Gaussian function has better simulation attenuation benefits than other functions. Therefore, in this paper, we propose to use the improved Ga2SFCA method with the following steps [9].

For each medical facility point j, search the number of people at each demand point k within the time threshold (d_0), assign weights using Gaussian equation and sum the weighted population to obtain the number of potential demanders at medical facility point j, and calculate the service capacity supply-demand ratio

$$R_j^{\mathrm{m}} = \frac{S_j^m}{\sum_{k \in (d_{kj} \le d_0^m)} D_k G(d_{kj}, d_0^m)} \tag{1}$$

m is the class type of the facility, and $R_{\mathrm{j}}^{\mathrm{m}}$ is the ratio of supply to demand of service capacity within the search time threshold for the jth m-type facility. $S_{\mathrm{j}}^{\mathrm{m}}$ is the supply capacity of facility j, which is expressed using the number of beds in this paper. The denominator in (1) is the total demand of facility j within the search time threshold. D_k denotes the population size of demand point k. d_{kj} denotes the cost of obtaining a visit

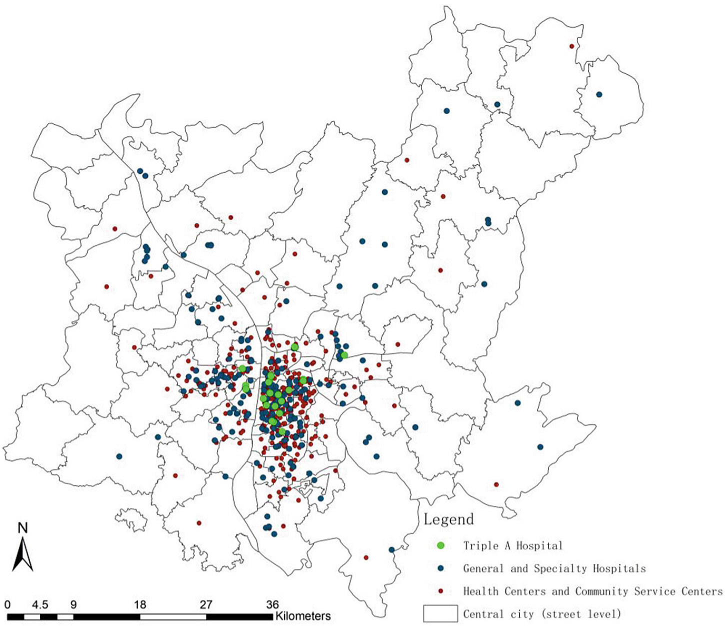


Fig. 1. Spatial distribution of three-level medical service facilities in the central city of Changsha

between points k and j, which is expressed using the time cost in this paper. d_0^m denotes the limiting travel time from the residential point to the m-class facility, and $G\left(\mathrm{d_{kj}}, d_0^m\right)$ is a Gaussian-type equation that takes into account the time impedance

$$G(d_{kj}, d_0^m) = \begin{cases} \frac{e^{-1/2\times(d_{kj}/d_0^m)^2 - e^{-1/2}}}{1-e^{-1/2}} & d_{kj} \le d_0^m \\ 0 & d_{kj} > d_0^m \end{cases} \quad (2)$$

The spatial accessibility index $A_{\mathrm{i}}^{\mathrm{m}}$ is calculated for each demand point i

$$A_i^{\mathrm{m}} = \sum_{j\in(d_{kj}\le d_0^m)} R_j^m G(d_{kj}, d_0^m) \quad (3)$$

Since the social equity connotation of public resources and income distribution is basically the same, the Lorenz curve method in economics [10] is introduced and defined as a method that reflects the relationship between the cumulative proportion p of the population and the proportion of resources corresponding to the occupied health service facilities. The line of perfect equality L(p) = p is a line with a slope of 1 through (0,0) and (1,1), and the health care facility resources are equally distributed when the proportion of the population and the possessed health care facility resources is p. However, in general, L(p) will lie below the line of perfect equality, and the farther it is from the line of perfect equality, the higher the degree of spatial mismatch between the distribution of medical service resources and population and the greater the degree of regional inequality, and vice versa.

4 Study Results

4.1 Accessibility of Medical Service Facilities at All Levels

Based on the improved Ga2SFCA method, the accessibility levels of medical service facilities at three levels in the central city of Changsha were evaluated under four modes of transportation travel. Under the private car mode of travel, there were significantly more streets with high accessibility of secondary medical services than primary and tertiary ones, and the streets with high accessibility of secondary medical services were mainly concentrated in Tianxin District, Yuhua District, Furong District and some streets in Kaifu District. Under the mode of public transportation and walking, the number of streets with high accessibility to secondary medical facilities is higher. Under the subway mode, the coverage of streets with high accessibility and higher accessibility of secondary and tertiary medical services is significantly better than that of primary.

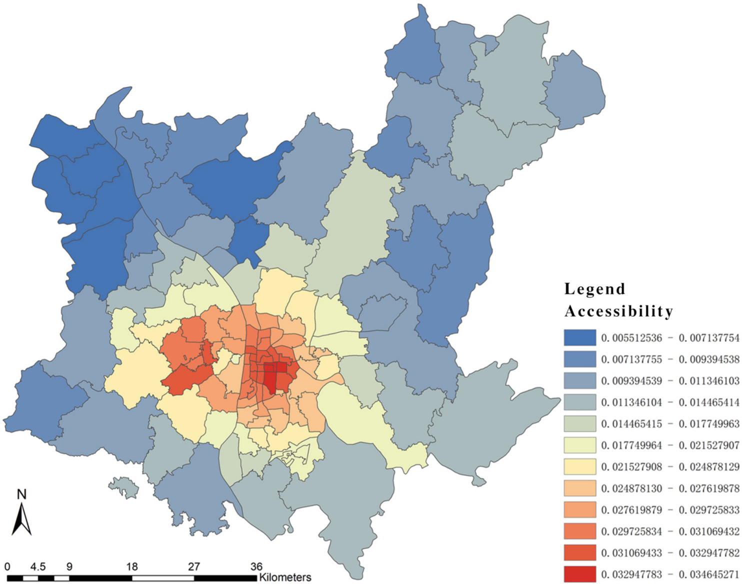
4.2 Comprehensive Accessibility of Medical Services

The accessibility values of the three levels of medical service facilities were weighted and superimposed on each of the four modes of travel, and equal weights were assigned to each of the three levels of medical service facilities. Under the private car travel mode, the overall accessibility of medical services showed a bicenter pattern of decreasing accessibility from the center to the periphery, with the southern part of the central city having better accessibility than the northern part. For the other three modes of travel, the integrated accessibility of medical services showed a monocentric pattern with decreasing accessibility from the center to the periphery (Fig. 2).

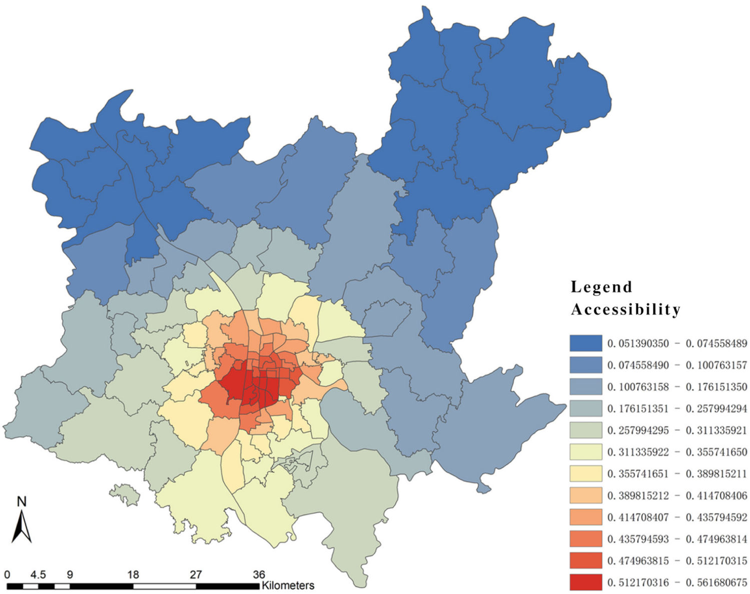
4.3 Lorenz Curve Analysis Based on Traffic Travel Mode

The accessibility of medical service facilities in each street under the improved Ga2SFCA method is essentially the resources of medical service facilities per capita in the street, so the accessibility values of medical service facilities in 119 streets in the central city of Changsha are ranked from the lowest to the highest, and the population is summed up to draw a Lorenz curve (Fig. 3).

The variation in the accessibility of medical services between streets is very obvious under the subway mode of travel, with nearly 23% of the population having almost 0. Under the bus mode of travel, the variation in the accessibility of medical services decreases significantly compared to the subway mode of travel, but is still significantly higher than that of private cars and walking trips, with 30% of the population having less than 15% of the medical services. In the case of private car trips, 30% of the population has nearly 20% of the health care facilities.

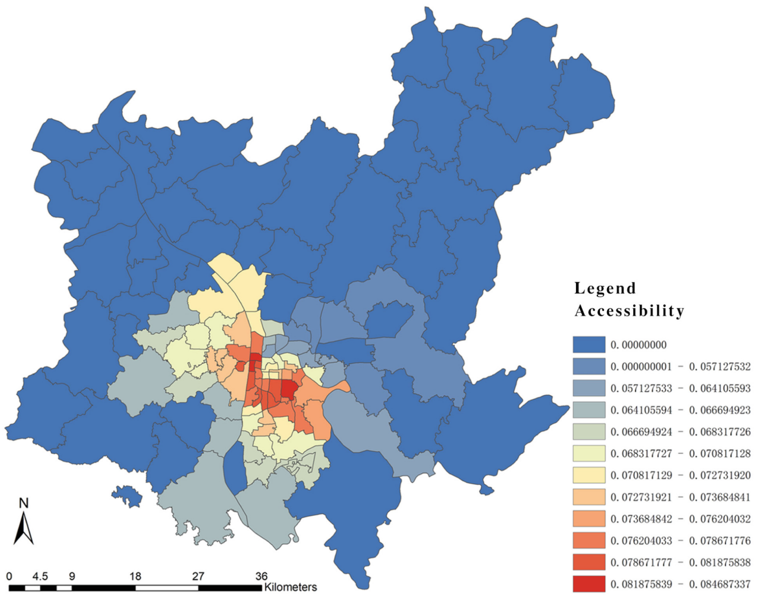


(a) Private car travel

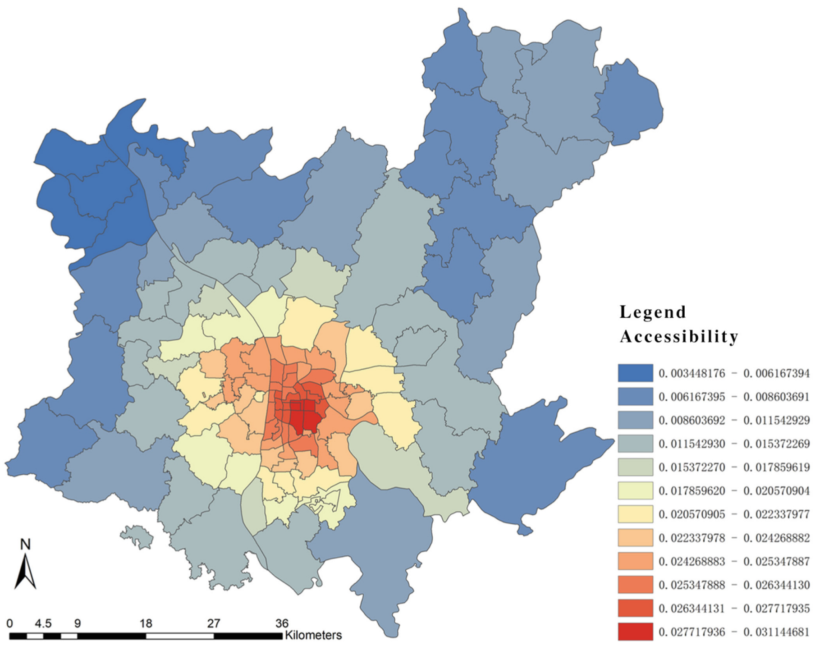


(b) Public transportation

Fig. 2. Spatial interpolation accessibility grading and street-level accessibility grading

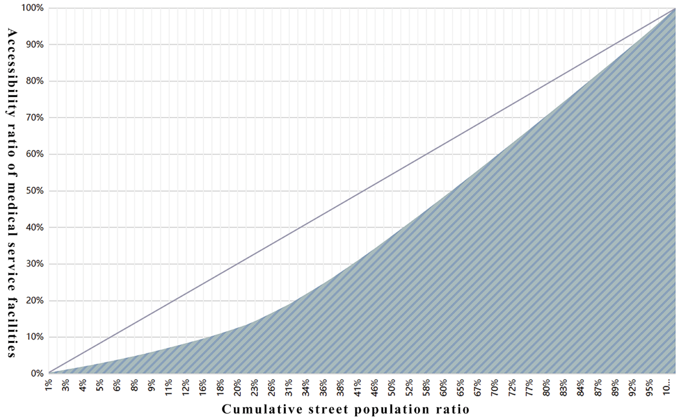


(c) Subway

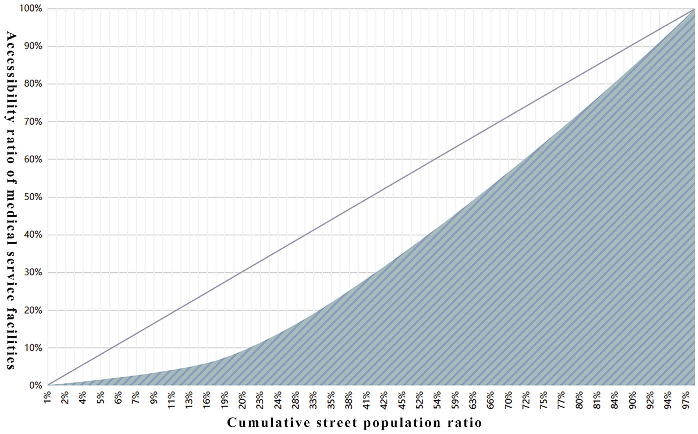


(d) Walking

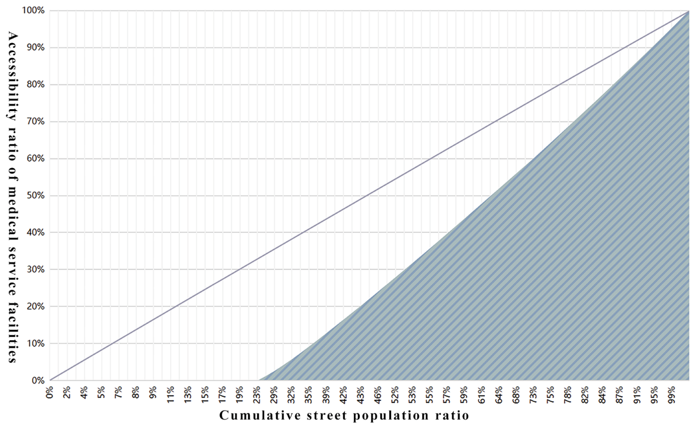
Fig. 2. (*continued*)



(a) Private car travel

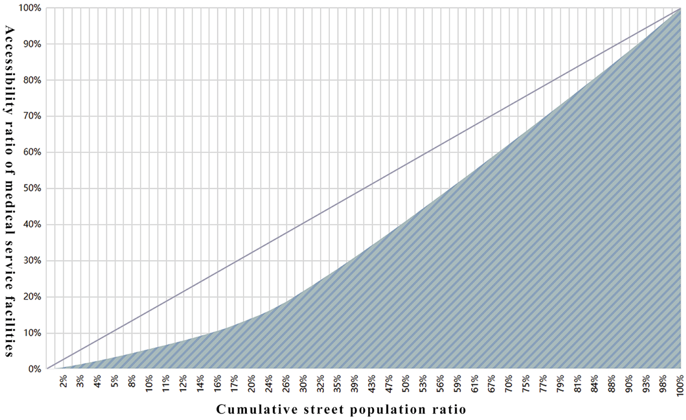


(b) Public transportation



(c) Subway

Fig. 3. Lorenz Curve Based on Transportation Mode

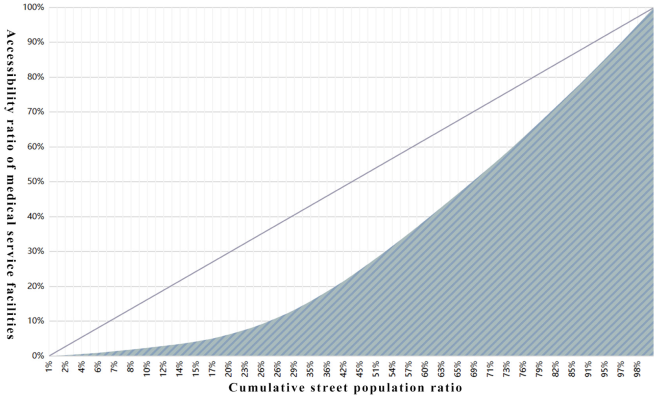


(d) Walking

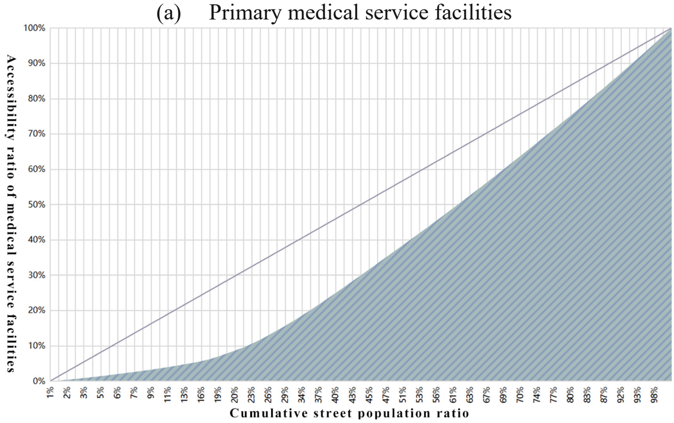
Fig. 3. (*continued*)

4.4 Lorenz Curve Analysis Based on the Equity of Access to Medical Resources by Class

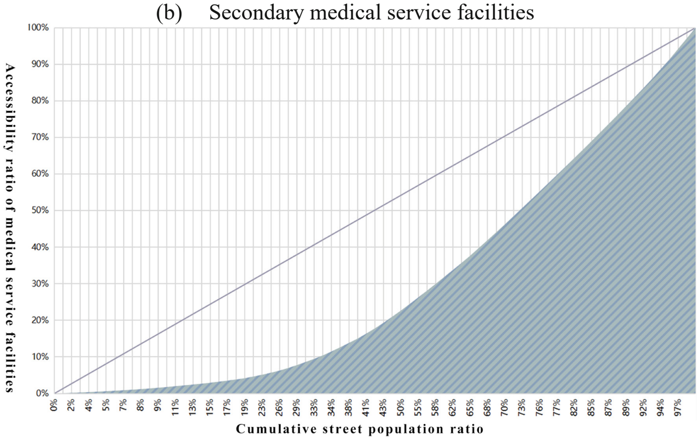
Before doing the Lorenz curve analysis, it is necessary to analyze the comprehensive accessibility of different levels of medical service facilities first. Taking the three types of levels of medical service facilities as the benchmark respectively, the spatial accessibility values under four types of medical access transportation modes are weighted and superimposed, and the significant influence of a certain type of medical access transportation mode on the analysis results is not avoided, and equal weights are given to each of the four medical access travel modes. It can be seen that the difference in the combined accessibility of secondary medical service facilities by multiple transportation modes is significantly smaller than that of primary and tertiary medical service facilities, with nearly 80% of the population occupying nearly 75% of secondary medical service facilities. The most significant variation in the combined multi-modal accessibility of tertiary care facilities was observed, with 80% of the population occupying less than 60% of tertiary care facilities (Fig. 4).



(a) Primary medical service facilities



(b) Secondary medical service facilities



(c) Tertiary medical service facilities

Fig. 4. Lorenz Curve Based on Equity in Access to Hierarchical Health Resources

5 Conclusion

In general, the degree of divergence in the equity of access to medical resources by class is more obvious compared with the equity of transportation modes. Among them, the difference of comprehensive accessibility by multiple transportation modes is significantly smaller for secondary medical service facilities than for primary and tertiary ones. In addition, medical service facilities show a more equitable spatial distribution pattern under walking travel mode, followed by private car travel mode. A reasonable distribution of transportation elements and the layout of medical resources of each level in the central city of Changsha should be carried out, with more emphasis on the latter.

However, this paper does not consider the distribution of different age, income and other factors of the group, and assumes that the population in the street is concentrated in the center of mass of the street, but the population in the street is not uniformly distributed, because the center of population distribution may not coincide with the geometric center of the street, which may cause imprecise analysis.

References

1. Li, F., Lai, Y.P., Yang, J.B. (2020) Thinking about the planning and construction of resilient healthy cities based on the new crown epidemic. In: the 2020 Annual Scientific and Technical Conference of the Chinese Society of Environmental Science. Nanjing. 4: 385–390.
2. Du, S.l. (2009) The redefinition of health care resources: A cognitive perspective based on a large resource view. China Health Economics, 28(05): 28-30.
3. Chen, F., Ji, X.F., Zhang, H.D. (2014) Advances in research on transportation equity in urbanization. Human Geography, 29(06): 10-17.
4. Zhan D.S., Zhang W.Z., Chen L., et al. (2019) Progress and trends of research on urban public service facility configuration. Advances in Geographical Sciences, 38(04): 506-519.
5. Langford, M., Higgs, G., Fry, R. (2016) Multi-modal two-step floating catchment area analysis of primary health care accessibility. Health and Place, 38: 70-81.
6. Radke, J., Mu, l. (2000) Spatial Decompositions, Modeling and Mapping Service Regions to Predict Access to Social Programs. Geographic Information Sciences, 6(02): 105-112.
7. Luo, W., Wang, F.H., (2003) Measures of Spatial Accessibility to Health Care in a GIS Environment: Synthesis and a Case Study in the Chicago Region. Environment and Planning B: Planning and Design, 30(06): 865-884.
8. Ji, X.F., Guan, H.T., Li, W., He, L. (2022) Evaluation of traffic equity for medical treatment in the central city of Kunming. Urban Transportation, 20(03): 119–125+82.
9. Farahani, R.Z., Hekmatfar, M., Fahimnia, B., et al. (2014) Hierarchical facility location problem: Models, classifications, techniques, and applications. Computers & Industrial Engineering, 68: 104-11.
10. Liu, S.K., Guan, X., Wang, B.W., et al. (2014) GIS-based evaluation study on the accessibility and equity of urban healthcare resources. China Health Business Management, 31(05):332-334.