Evaluating the inequality of medical resources allocation based on spatial and non-spatial accessibility: A case study of Wenzhou, China

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Research Article

Keywords: Spatial accessibility, Disparities, Medical resources, Resource allocation, Hierarchical two-step floating catchment area method (H2SFCA)

Posted Date: April 21st, 2022

DOI: https://doi.org/10.21203/rs.3.rs-1568011/v1

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Abstract

**Background:** Environmental and social factors that impact resource allocation in rural, developing regions are key social determinants of health that require multi-sector collaboration to improve health opportunities. Thus, we sought to evaluate the spatial distribution and accessibility of medical resources to assess current disparities, determine best practices for resource allocation, and inform policies to improve regional health planning.

**Methods:** We used the Gini coefficient and agglomeration degree to measure inequality among the frequency distribution of medical resources in Wenzhou, China. We applied the modified hierarchical two-step floating catchment area (H2SFCA) method to evaluate the spatial accessibility of medical institutions across the city. Finally, we explored the influencing factors of accessibility differences using the spearman correlation analysis.

**Results:** The distribution of medical resources in Wenzhou is inequitable according to population and geographical distribution. The overall spatial accessibility of Wenzhou is poor, the accessibility of east region is higher than west region, and the accessibility of different levels of medical institutions varies greatly. Accessibility is positively correlated with the number of institutions ($p=0.585$), the number of doctors ($p=0.670$), population density ($p=0.769$), road density ($p=0.792$), and GDP ($p=0.310$).

**Conclusions:** There are disparities in the spatial and unbalanced distribution of medical resources in Wenzhou. Policies and initiatives to improve the geographical distribution of resources, construct connected road networks, and enhance resident access to medical resources are needed.

**Background**

One of the United Nation's 2030 global strategic goals is ensuring healthy lives and promoting well-being for all individuals, which includes access to quality healthcare services [1]. However, with the acceleration of urbanization and increased population density in urban regions facilitated by migration, challenges for equitable and effective allocation of medical resources have arisen. The unequal distribution of medical resources has compromised public health and safety and intensified social conflicts[2]. The emergence of the COVID-19 pandemic has further contributed to resource scarcity with strains on existing medical infrastructure[3]. Since reform and opening up, with the improvement of the market-oriented economy in China, the existing medical resources and services are difficult to meet the needs of rapid economic growth and the aging population [4]. Currently, the supply of medical resources in China presents an "inverted triangle " mode, that is, high-quality medical resources are mainly concentrated in metropolis and large hospitals, while grassroots medical institutions have few high-quality talents and poor service ability. Most medical resources and patients are concentrated in tertiary hospitals which account for 8% of the total number of medical institutions, and tertiary hospitals are mainly distributed in urban regions [5]. Moreover, the income gap between regions was widening, which led to the unbalanced development of regional medical and health infrastructure and the unbalanced distribution and allocation of medical resources. Although many efforts have been made to rationalize the allocation of medical resources, problems such as imbalance distribution, regional sharing and poor mobility of medical resources still exist[6].

Medical resources are allocated in the same way as public facilities. The main idea first proposing by Teitz was to allocate public facilities according to the rules of maximizing efficiency and fairness, taking into account their location, accessibility, distribution pattern, impact on the city and its externalities[7]. Among them, accessibility is a decisive factor affecting the level of equalization of medical services. The accessibility of medical institutions not only reflects the public's access and convenience to medical services, but also affects the improvement of residents’ quality of life [8]. Accessibility is affected by both spatial and non-spatial factors: spatial factors mainly include the distance or the time cost from the residential areas to hospitals; non-spatial factors include the attribute characteristics of medical institutions (such as scale, grade, quantity), as well as the residents’ own attributes (economic income, medical preference, transportation vehicle, and number of residents) [9]. The methods to measure spatial accessibility mainly include the ratio method [10], the nearest distance method [11], the gravity model [12], the Huff model [13] and the two-step floating catchment area (2SFCA) method [14].

Among all the mentioned methods, the 2SFCA method is widely used in recent studies to show accessibility to health care facilities [15–19]. It comprehensively considers the effects of the supply, the demand and their distance and it is more intuitive to interpret and easier to calculate. However, the 2SFCA has received sharp criticism because of distance decay which represents the attraction of medical institutions to residents has decreased with distance increase [20]. To overcome this shortcoming, a number of researchers have tried to improve the 2SFCA methods. Luo and Qi [21] presented an enhanced two-step floating catchment area (E2SFCA) method which assigns different weights associated with different travel time zones. Dai [22] added a Gaussian function to model the distance decay effect. Wang et al. [23] investigated the difference in medical treatment between minority areas and non-ethnic minority areas in Sichuan Province based on the modified 2SFCA method. On the other hand, some studies have tried to improve the 2SFCA method by integrating non-spatial factors. Wang et al. [24] showed accessibility to primary care facilities by integrating spatial and non-spatial factors when defining health professional shortage areas. McGrail et al. [25] proposed an index of rural access to primary care by integrating health needs and mobility within the 2SFCA algorithm. Jin et al. [26] proposed a hierarchical two-step floating catchment area (H2SFCA) method to evaluate the spatial accessibility of public medical resources considering the factors at different levels of medical resources. In this study, we aim to evaluate the accessibility and equality of medical institutions at different levels, so modified H2SFCA methodology with both spatial and non-spatial impact factors is used.

Wenzhou, an economically developed city in eastern coastal of China, is chosen as a case study area. Wenzhou’s geography is mostly mountainous and islands surrounded by water. This unique geomorphic features lead to uneven urban development and regional differences in medical resource allocation. Therefore, the study objectives include: the traditional health economics method is applied to identify whether medical resources are distributed equally across the population and the regions, and then we used the accessibility analysis method to investigate whether medical institutions at all levels (especially primary health care centers) can meet the medical needs of local residents. Thus, the study results and understandings can be helpful to guide the reasonable distribution and flow of medical resources in Wenzhou, and then provide theoretical guidance for improving living standards and promoting the equality of medical resource allocations in that region.
Methods

Study Area

Wenzhou municipal region is selected as the study area, and it located in the southeast of Zhejiang Province, China, and is the economic center of southern Zhejiang (Fig. 1). The total area of the municipal region is 12,109 km². By the end of 2019, Wenzhou had a permanent population of 9.30 million, registered population of 8.32 million, per capita GDP of 71,225 yuan. There are 12 administrative districts in Wenzhou, including 4 central urban districts: Lucheng District (LC), Longwan District (LW), Ouhai District (OH), Dongtou District (DT), 5 counties: Yongjia County (YJ), Pingyang County (PY), Cangnan County (CN), Wencheng County (WC), Taishun County (TS) and 3 county-level cities: Ruian City (RA), Yueqing City (YQ), Longgang City(LG). Moreover, 185 subdistricts are divided up based on the current urban districts and counties, including 67 urban subdistricts and 118 towns.

In order to meet the medical and health needs of residents, Wenzhou has continuously improved the level of medical infrastructure and optimized the layout of medical resources in recent decades. From 1978 to 2019, the number of medical institutions increased from 877 to 5,794, the number of beds increased from 5,826 to 44,038, the number of doctors increased from 4,551 to 30,136, and the number of nurses increased from 1,306 to 29,219 according to the Wenzhou Statistical Yearbook and Wenzhou Local Chronicles Healthcare Development Statistical Bulletin.

Data Sources

Demographic and economic data

The population data used in this study was obtained from the Wenzhou Statistical Yearbook 2020. The geometric central point of the subdistrict/town shape was used as the population centroid. The population data coordinate was referenced as CGS2000. The GDP data was derived from the Resources and Environment Science and Data Center and Wenzhou Statistics Bureau[27].

Medical Institutions data

The medical institution data used in this research was from the National Health Commission of the People’s Republic of China and the corresponding official websites, mainly including level categories and doctor numbers; The total number of beds and health personnel in each district and county were obtained from the Wenzhou Health Commission. The location information of medical institutions was obtained through manual search in Tianditu Map of Wenzhou(website). The medical institutions included general hospitals and community health centers in Wenzhou. In addition, considering that the specialized hospitals were highly irreplaceable, and their spatial layout had little impact on residents’ medical treatment, so the specialized hospitals were excluded in this study. In the end, we selected 90 general hospitals and 200 community health centers. From a hierarchical perspective, the medical institutions in China were divided into four levels: tertiary hospitals, secondary hospitals, primary hospitals and community health centers according to their different service scopes. The distribution of medical institutions is shown in Fig. 1.

Road Network

The road network data was collected from the Land and Resources Bureau, and its coordinate system reference was WGS-1984. Based on the Technical Standard of Highway Engineering (JTG B01-2014) [28] and the local actual situation in Wenzhou, the average speed of different types of roads were set as follows: highways 100km/h, fast-speed roads 80 km/h, national and provincial roads 70 km/h, urban first class roads 50 km/h, county roads, town roads, urban second and third class roads 40 km/h, urban fourth class roads 30km/h. The distribution of road networks is shown in Fig. 1.

Statistical Analysis

Gini Coefficient

In economics, the Gini coefficient was an internationally common indicator that illustrate income gap of residents in a country or region. In recent decades, it was widely used to measure the equality of medical resource allocation in terms of demographic and geographical aspects [29]. We used it to examine the equality of institutions, beds, doctors and nurses by population and geographical distribution in this study. The following formula is employed to calculate the Gini coefficient:

$$ G = \sum_{i=1}^{n} W_i Y_i + 2 \sum_{i=1}^{n} W_i (1 - V_i) - 1 $$

In formula (1), $G$ is the Gini coefficient; $W_i$ is the cumulative proportion of $i$ population or geographic area; $Y_i$ is the corresponding cumulative proportion of the medical resources; $V_i = Y_1 + Y_2 + ... + Y_n$ is the fractional rank in terms of per capita medical resources from the lowest number to the highest number.

The Gini coefficient ranges from 0 to 1; a value of 0 indicates equitable distribution of resources or services [30], a value of less than 0.2 means absolutely fair; a value of 0.2–0.3 means fair; a value of 0.3–0.4 means basic fair; a value of greater than 0.4 triggers an alert of inequality, and above 0.6 reflects high inequality [31].

Agglomeration degree

The Gini coefficient can only measure the equality of the overall resource allocation, and cannot analyze the specific situation within region. Thus, We further used agglomeration degree to measure the equality and existing differences of medical resource allocation in each district and county of Wenzhou, so as to make up for the deficiency of the Gini coefficient [32]. Health resource agglomeration degree, it showed the proportion of health resources in a certain region that occupied 1% of the land area of the country. The calculation formula is as follows:
In formula (2), $HRAD_i$ is the health resource agglomeration degree in the $i$ region, $HR_i$ is the number of health resources in the $i$ region, $A_i$ is the land area in the $i$ region, $A_n$ is the land area of country, $HR_n$ is the total number of health resources in country.

Population agglomeration degree, it was defined as the proportion of population in a certain region that occupied 1% of the land area of country, and the calculation formula is as follows:

$$PAD_i = \frac{(P_i/P_n) \times 100\%}{(A_i/A_n) \times 100\%} = \frac{P_i/A_i}{P_n/A_n}$$

In formula (3), $PAD_i$ is the population agglomeration degree in the $i$ region, $A_i$ and $A_n$ have the same meaning as above. $P_i$ is the number of population in the $i$ region, $P_n$ is the total population in the country.

Evaluation criteria: When the agglomeration degree of health resources is greater than 1, indicating that health resources are relatively more equitable in terms of geographical distribution. When the ratio of HARD and PAD is close to 1, the health resources in this region meet the medical needs of the population, and the residents have better access to health services. If the ratio is greater than 1, it indicates that the health resources in this region are overpopulated; if the ratio is less than 1, it indicates that the resources are insufficient [33].

Network Analysis

In order to assess spatial accessibility, we utilized the origin and destination (OD) cost matrix in network analysis toolbox of ArcGIS 9.3 (ESRI Inc.) to calculate the travel time costs from each residential area to all medical institutions. Also, the shortest path analysis in the network analysis module was applied to estimate the travel time costs from residential areas to the nearest community health center and general hospital, respectively.

Assessing Accessibility Using the modified H2SFCA method

The two-step floating catchment area (2SFCA) method, first proposed by Radke and Mu[14], it considers both the demand side and the supply side. The method starts from the supply and demand points respectively and moves the search twice. In the first step, for each supply location $j$, we search all demand locations $k$ within the search radius $d_0$ and calculate the supply-demand ratio $R_j$.

The formula is:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} D_k}$$

In Formula (4), $S_j$ represents the capacity of supply at location $j$, $d_{kj}$ is the travel time between demand $k$ and supply $j$, $D_k$ is the population at the demand location.

In the second step, for each demand location $i$, we search all supply locations $j$ within the search radius $d_0$ and sum up the supply-to-demand ratios $R_j$.

The formula is:

$$A_i^k = \sum_{j \in \{d_{ij} \leq d_0\}} R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq d_0\}} D_k}$$

In Formula (5), $A_i^k$ is the accessibility score of the demand location $i$, $d_{ij}$ is the travel time between demand $i$ and supply $j$.

The limitation of the traditional 2SFCA method is that they adopt a dichotomous distance decay function supposing that all people with a catchment size use service equally. To address the deficiency, this paper adopted the modified H2SFCA method of determining catchment size according to different levels of medical institutions, which comprehensively considers non-spatial factors such as grade and number of doctors. The model expression is as follows:

$$A_i = \sum_j \sum_{d_{ij} \leq d^j} \frac{S_j^j(d_{ij})}{\sum_k d_{kj} \leq d^j} P_k R(d_{kj})$$
where $A_i$ is the accessibility at demand location $i$ in a hierarchical system; $l$ is the level of medical institutions in the system; $S_{ij}^l$ is the doctors of institution $j$ at level $l$, $D^l_i$ is the catchment size for institutions at level $l$, and other variates have the same meaning as Formula (4) and (5). The distance decay function $f(d_{ij})$ take the gravity power function form as follows:

$$f(d_{ij}) = \begin{cases} d_{ij}^{-\beta}, & d_{ij} \leq D^l_i \\ 0, & d_{ij} > D^l_i \end{cases} \quad (7)$$

Where $\beta$ is the distance-decay parameter. Most of the values of $\beta$ in the existing studies lies between 0.9 and 2.29\cite{34}, Wang and Zhang conducted a sensitive analysis on $\beta$, setting $\beta$ as 1 or 2 respectively. In conclusion, they thought that $\beta = 2$ could be better measure the accessibility of medical services \cite{35}.

Therefore, this study set $\beta$ to 2. Considering the abundant medical resources and advanced medical technology in tertiary hospitals, $D^l_i$ for tertiary hospitals was set to 190min which is the maximum distance between each tertiary hospital and residential area. The $D^l_i$ was set as 45min for secondary hospitals, and 15min for primary hospitals and community health centers.

According to the distribution of the accessibility scores, we disposed accessibility scores by means of Natural Breaks Classification, dividing it into seven levels, respectively, Worst, Worse, Bad, General, Good, Better and Best.

**Results**

**General description of medical institutions**

In 2019, there were 5794 medical institutions in Wenzhou, with 4.74 beds per thousand people, 3.24 doctors per thousand people and 3.14 nurses per thousand people. The number of beds, doctors and nurses per thousand people in LC is higher than the average level of Wenzhou, while other districts and counties are lower than the average level of the city.

It can be seen from Table 1 that there are great differences in the distribution of medical resources in Wenzhou. Medical institutions (especially tertiary hospitals) are mainly clustered in LC, followed by RA, YQ and PY. DT and LG have the least number of medical institutions. Separately, the number of general hospitals in WC, TS and DT is the fewest, and the number of health centers in LG, DT and LW is the least. According to the outline of China’s medical and health service system planning (http://www.gov.cn), by 2020, there will be 6 beds per thousand resident population, 2.5 doctors per thousand resident population, and 3.14 nurses per thousand resident population. By comparing with national standard, the number of beds per thousand people in Wenzhou is lower than the national standard, the number of doctors per thousand people is higher than the national standard, and the number of nurses per thousand people is close to the national standard.

<table>
<thead>
<tr>
<th>Town</th>
<th>Number of Counties</th>
<th>Area (km²)</th>
<th>Population (thousands)</th>
<th>Road length (km)</th>
<th>GDP (billion yuan)</th>
<th>Number of Medical institutions</th>
<th>Number of beds</th>
<th>Number of doctors</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Tertiary hospitals</td>
<td>Secondary hospitals</td>
<td>Primary hospitals</td>
</tr>
<tr>
<td>LC</td>
<td>14</td>
<td>293</td>
<td>785.503</td>
<td>1360947.26</td>
<td>1137.13</td>
<td>6</td>
<td>3</td>
<td>9</td>
</tr>
<tr>
<td>LW</td>
<td>10</td>
<td>319</td>
<td>340.465</td>
<td>1046656.15</td>
<td>704.52</td>
<td>1</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>OH</td>
<td>13</td>
<td>466</td>
<td>463.236</td>
<td>1670972.66</td>
<td>661.12</td>
<td>3</td>
<td>2</td>
<td>2</td>
</tr>
<tr>
<td>DT</td>
<td>7</td>
<td>254</td>
<td>154.905</td>
<td>393669.05</td>
<td>107.84</td>
<td>0</td>
<td>1</td>
<td>2</td>
</tr>
<tr>
<td>YJ</td>
<td>22</td>
<td>2677</td>
<td>987.881</td>
<td>3150959.59</td>
<td>444.52</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>PY</td>
<td>16</td>
<td>1042</td>
<td>884.456</td>
<td>2271744.88</td>
<td>510.29</td>
<td>1</td>
<td>2</td>
<td>4</td>
</tr>
<tr>
<td>CN</td>
<td>18</td>
<td>1069.01</td>
<td>969.668</td>
<td>2433606.67</td>
<td>351.7</td>
<td>1</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>WC</td>
<td>17</td>
<td>1296</td>
<td>410.794</td>
<td>1891943.46</td>
<td>104.91</td>
<td>0</td>
<td>2</td>
<td>1</td>
</tr>
<tr>
<td>TS</td>
<td>19</td>
<td>1768</td>
<td>372.968</td>
<td>2403271.97</td>
<td>110.6</td>
<td>0</td>
<td>2</td>
<td>0</td>
</tr>
<tr>
<td>RA</td>
<td>23</td>
<td>1350</td>
<td>1258.202</td>
<td>2994816.06</td>
<td>1003.96</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>YQ</td>
<td>25</td>
<td>1391</td>
<td>1314.915</td>
<td>3026750.25</td>
<td>1209.93</td>
<td>1</td>
<td>5</td>
<td>6</td>
</tr>
<tr>
<td>LG</td>
<td>1</td>
<td>183.99</td>
<td>380.654</td>
<td>502226.54</td>
<td>300.51</td>
<td>0</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

**Equality in the distribution of medical resources**

As shown in Table 2, from the distribution of population, the $G$ of medical institutions is far below 0.2, meaning absolute fair; the $G$ of doctors is between 0.2 and 0.3, meaning fair; the $G$ of beds is between 0.3–0.4, meaning basic fair; the $G$ of nurse exceeds 0.6, meaning high inequality. It illustrates that the distribution of medical institutions by population is the best, and the distribution of nurses by population is the worst. In addition, except for medical
Institutions, the Gini coefficients of beds, nurses and doctors by geography are higher than 0.5, exceeding the “equality alert line of 0.4”, of which the G of doctors is 0.667, indicating that the distribution of these medical resources (particularly doctors) by geography is unfair. Comparing the Gini coefficient by population and geography, it can be concluded that the distribution of beds and doctors according to population relatively balance, but they are unreasonable in terms of geographical allocation; The distribution of nurses is unreasonable whether it is allocated according to population or geographical regions. Obviously, in 2019, the allocation of medical resources in Wenzhou city has the phenomenon of agglomeration, especially in terms of space.

From the analysis of regional classification (Table 3), the agglomeration degree of various medical resources in LC, LW, YQ and LG is all greater than 1, and LC is much higher than other regions, indicating that the four regions have higher equality according to geographical allocation. In contrast, the agglomeration degree of various medical resources in DT, YJ, WC, and TS is all less than 1, indicating that these regions have lower equality according to geographical distribution. The agglomeration degree of institutions, beds, doctors and nurses in LC is 22 times, 90 times, 60 times and 100 times of TS, respectively. From the ratio of health resource agglomeration to population agglomeration, the ratios of various medical resources in LC are greater than 1, indicating that the medical resources in LC are surplus relative to population size; The ratios of institutions, doctors and nurses in LW, OH and RA are greater than or close to 1, while the ratio of beds is less than 1, indicating that the number of institutions and medical human resources in these regions are relatively abundant compared with the hardware facilities; the ratios of various medical resource in other districts and counties are all less than 1, which indicates that the medical resources in these regions are unable to meet the needs of the local residents.

Table 2
Gini coefficients for medical resources in Wenzhou, 2019.

<table>
<thead>
<tr>
<th>Medical resources</th>
<th>Population</th>
<th>Geography</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of medical institutions</td>
<td>0.057</td>
<td>0.232</td>
</tr>
<tr>
<td>Number of beds</td>
<td>0.332</td>
<td>0.514</td>
</tr>
<tr>
<td>Number of doctors</td>
<td>0.232</td>
<td>0.667</td>
</tr>
<tr>
<td>Number of nurses</td>
<td>0.605</td>
<td>0.505</td>
</tr>
</tbody>
</table>

Table 3
Agglomeration degrees of population and medical resources in Wenzhou, 2019.

<table>
<thead>
<tr>
<th>Town</th>
<th>Population</th>
<th>Institutions</th>
<th>Beds</th>
<th>Doctors</th>
<th>Nurses</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>value</td>
<td>ratio</td>
<td>value</td>
<td>ratio</td>
<td>value</td>
</tr>
<tr>
<td>LC</td>
<td>3.75</td>
<td>4.11</td>
<td>1.10</td>
<td>15.3</td>
<td>4.08</td>
</tr>
<tr>
<td>LW</td>
<td>1.89</td>
<td>3.01</td>
<td>1.59</td>
<td>1.08</td>
<td>0.57</td>
</tr>
<tr>
<td>OH</td>
<td>1.39</td>
<td>1.92</td>
<td>1.38</td>
<td>0.86</td>
<td>0.62</td>
</tr>
<tr>
<td>DT</td>
<td>1.18</td>
<td>0.89</td>
<td>0.75</td>
<td>0.54</td>
<td>0.46</td>
</tr>
<tr>
<td>YJ</td>
<td>0.52</td>
<td>0.43</td>
<td>0.83</td>
<td>0.31</td>
<td>0.60</td>
</tr>
<tr>
<td>PY</td>
<td>1.28</td>
<td>1.31</td>
<td>1.02</td>
<td>1.05</td>
<td>0.82</td>
</tr>
<tr>
<td>CN</td>
<td>1.31</td>
<td>1.01</td>
<td>0.77</td>
<td>1.11</td>
<td>0.85</td>
</tr>
<tr>
<td>WC</td>
<td>0.44</td>
<td>0.22</td>
<td>0.50</td>
<td>0.18</td>
<td>0.41</td>
</tr>
<tr>
<td>TS</td>
<td>0.30</td>
<td>0.18</td>
<td>0.61</td>
<td>0.17</td>
<td>0.58</td>
</tr>
<tr>
<td>RA</td>
<td>1.39</td>
<td>1.60</td>
<td>1.51</td>
<td>0.99</td>
<td>0.71</td>
</tr>
<tr>
<td>YQ</td>
<td>1.43</td>
<td>1.55</td>
<td>1.09</td>
<td>1.03</td>
<td>0.72</td>
</tr>
<tr>
<td>LG</td>
<td>3.57</td>
<td>3.50</td>
<td>0.98</td>
<td>1.69</td>
<td>0.47</td>
</tr>
</tbody>
</table>

Travel time cost from the residential areas to nearest medical institutions
Analyzed by the shortest path analysis, we obtain the shortest travel time cost from the residential areas to the nearest health centers and the nearest general hospitals, respectively (Fig. 2). The lower the travel time cost to the nearest medical institution, the better accessibility is to residents. Reaching the nearest health center takes 6.41 min on average, 166 residential areas (89.73%) can obtain medical services from health centers within 15min, and 17 residential areas (9.19%) are covered within 15-30min. Only one residential area need more than 30min to access the nearest health center, which is located in the eastern edge of YJ. Reaching the nearest general hospital takes 21.38 min on average, more than half of residential areas (51.89%) can obtain medical services from general hospitals within 15min, 36 residential areas (19.46%) can obtain medical services from general hospitals within 15-30min, 28 residential areas (15.14%) are covered within 30-45min, but 9 residential areas need exceed 60min to access the nearest general hospital, mainly concentrated in the northwestern region of YJ and the northern region of TS, which are lack of high-grade roads and have poor accessibility. In addition, there are 4 residential areas that cannot reach general hospitals within 180 minutes, which are located on the islands of DT, RA and PY. Mostly due to the lack of medical resources and road network connections, it is not possible for residents to access medical treatment within medically required time.
Spatial Accessibility of Medical Institutions at all levels

Based on the modified H2SFCA, the overall accessibility in Wenzhou was obtained by summing the accessibility to the all levels of medical institutions. The accessibility score represents the number of doctors in medical institutions per thousand population. The higher the accessibility score is, the more medical resources per capita in the region are available. As shown in Fig. 3a, the overall spatial accessibility of medical institutions in Wenzhou has obvious variation. The residential areas with accessibility in grade of Best are less, and the residential areas with accessibility in grade of General and below account for most of areas (n = 144), so the overall accessibility is poorer. The areas with highest overall accessibility are concentrated in the urban central areas, such as LC. The spatial accessibility of RA and YQ is relatively good, while the spatial accessibility is relatively poor in WC and TS. On the whole, spatial accessibility of the east is higher than that of the west.

There are significant differences in the distribution of accessibility of medical institutions at all levels (Fig. 3b-d). The distribution of accessibility to tertiary hospitals is the most uneven, showing an obvious cluster of urban centers. The tertiary hospitals in LC have the highest accessibility, which is basically consistent with the distribution of tertiary hospitals. Unlike tertiary hospitals that have strong central accessibility, the accessibility of secondary hospital in LC is no longer the best at this level. The reason for this phenomenon is that LC has the highest population density, while the distribution of secondary hospitals is scattered and relatively even in most areas. The spatial accessibility of primary hospitals among various levels of medical institutions is the worst, and TS has the lowest accessibility, because there is no primary hospital in TS. The distribution of the accessibility of health centers is relatively even, but the accessibility scores of health centers in most residential areas are not high, which are at General and below (n = 185), the main reasons are the number of doctors in health centers is small and the supply capacity of medical resources is limited.

According to Fig. 4, it can be seen that the overall accessibility of more than 3/4 of the residential areas is General and below, including 64.5% of the population, while the overall accessibility in grade of Good and above only covers 22.2% of the residential areas, but it contains 35.5% of the population, which indicates that the overall accessibility of Wenzhou is poor, and the population is relatively concentrated in areas with better accessibility. In tertiary hospitals and secondary hospitals, the proportion of residential areas with accessibility in grade of Bad and above exceeds 80%, covering 4/5 of the population, indicating that the vast majority of residents cannot obtain high-grade medical services. Additionally, the accessibility grades of primary hospitals and health centers are all General and below, which shows that the service level of primary hospitals and health centers is poor and the existing medical service level needs to be improved.

Correlations between spatial accessibility and influence factors

Accessibility scores (Table 4) are positively correlated with the number of medical institutions, the number of doctors, population density, road density and GDP with the strongest correlation with road density and weakest correlation with GDP. The larger the number of medical institutions, the wider the choice of medical treatment for residents, and the higher the accessibility score. There is a strong positive correlation between the number of medical institutions and the number of doctors, the more medical institutions, the more doctors. Therefore, most doctors will choose to go to the regions where medical resources are concentrated, resulting in a large difference in the accessibility score. The higher the road density, the better the accessibility, and the more convenient it is for residents to obtain medical treatment. Consequently, most medical institutions will be built near the road network, and road density is one of the main reasons for the difference in accessibility. The areas with higher population density, accessibility is better, and the number of accessible hospitals is relatively large, which can meet medical needs of residents. The economically developed areas have relatively better accessibility, such as LC, YQ and RA, which are economically developed and have better accessibility to hospital.

<table>
<thead>
<tr>
<th>Analysis index</th>
<th>Accessibility score</th>
<th>Number of medical institutions</th>
<th>Number of doctors</th>
<th>population density</th>
<th>Road density</th>
</tr>
</thead>
<tbody>
<tr>
<td>Number of medical institutions</td>
<td>0.585**</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of doctors</td>
<td>0.670**</td>
<td>0.799**</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Population density</td>
<td>0.769**</td>
<td>0.493**</td>
<td>0.590**</td>
<td></td>
<td></td>
</tr>
<tr>
<td>(person/km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Road density</td>
<td>0.792**</td>
<td>0.512**</td>
<td>0.592**</td>
<td>0.826**</td>
<td></td>
</tr>
<tr>
<td>(km/ km²)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>GDP(ten thousand)</td>
<td>0.310**</td>
<td>0.374**</td>
<td>0.536**</td>
<td>0.326**</td>
<td>0.266**</td>
</tr>
</tbody>
</table>

Note: ** Significant at 0.01 level (two-tailed)

Discussion

The spatial distribution of medical resources is unbalanced, and the geographical equality needs to be improved

The geographical distribution of all medical resources in Wenzhou is highly unfair, and similar results have also appeared in other studies[36, 37]. On the one hand, this is related to the allocation of resources in China, which usually takes the amount of health resources per thousand population as the main indicator [38]. However, this method does not take into account geographical factors of medical resources allocation, resulting in the concentration of medical resources in densely populated areas. On the other hand, the allocation of medical resources is positively correlated with the level of regional economic
development, and well-developed regions often have relatively higher levels of medical resource allocation[39]. Consequently, it is suggested that the government should pay more attention to geographical equality when formulating regional planning, improve the mechanism of medical resource allocation, and allocate more medical resources to remote and underdeveloped areas in order to improve the equity of health resource allocation[40]. For the problems of excessive medical resources in central urban areas such as LC and lack of medical resources in districts and counties such as TS, corresponding measures should be taken to promote the sinking of medical resources to each district and country to achieve cross-regional flow of resources. In view of large disparities in resources among districts and counties in Wenzhou, the government should adopt macro-control, formulate regional health planning by considering various factors such as population, geography and economic level, so as to narrow the differences of medical resources allocation among regions.

The nurses are highly unevenly distributed by population and geography. Due to the influence of geographical location, medical staff are more inclined to choose employment in central urban areas, which can easily lead to excessive concentration of talents in the central city, while medical staff in remote areas are in short supply. Hence, it is suggested that the government should put the equality of nursing resources at the top of the task of improving health human resources. First, it is necessary to increase the investment of health human resources, improve the nursing performance system, raise the welfare of nursing staff and enhance the stability of nursing team. second, it should issue corresponding employment guidance policies to encourage college graduates to choose employment in remote urban areas, and give preference to these personnel in terms of staffing, professional title promotion [41]. Third, strengthen the flow of nursing staff, implement counterpart assistance and increase further study opportunities to improve the theoretical and practical level of primary nurses. Ultimately, it will promote the balanced distribution of nursing resources across different regions, populations and medical institutions at all levels to ensure the accessibility of medical services.

**Obvious differences in the accessibility of medical resources at all levels, and “graded diagnosis and treatment” policy needs to be strengthened**

By comparing the travel time and cost to the nearest medical institutions with the spatial distribution of the overall accessibility score, it is found that the smaller the travel time cost from residential areas to the nearest medical institutions, the more convenient it is for residents to travel, the higher the accessibility score in this area and the large number of accessibility hospitals.

The overall spatial accessibility of Wenzhou is poor and the heterogeneity is obvious. LC has the highest accessibility, and WC and TS have poor accessibility. The reason for this gap is the unequal distribution of medical resources. LC is the central city with dense population, developed economy, convenient transportation, and supported by medical university, which gathers a large number of high-quality medical resources. While WC and TS are located in the southwest, where the economic development is relatively lagging behind, the government's investment in medical resources is insufficient, coupled with the scarcely populated area, low road density, long travel time for residents, resulting in low access to healthcare services. It is suggested that government should actively strengthen the road networks construction in remote areas, especially WC, TS and the northwest of YJ. In addition, the areas with higher accessibility not only exist in the central city, but also some towns, such as the northwestern part of LW, where the population density is lower and the per capita acquisition of medical resources are relatively sufficient. On the whole, spatial accessibility of the east is higher than that of the west. The main reasons for this spatial difference are terrain and altitude[9]. The eastern part is a plain area with low altitude and good medical conditions; the western part is a middle-low mountain area with relatively high altitude, high travel cost and poor accessibility.

The accessibility of medical institutions at all levels has significantly different. In order to improve the spatial accessibility and reduce the inequality of medical services at all levels, it is necessary to take corresponding measures for different levels of medical institutions. For tertiary hospitals, building new high-grade hospitals in the periphery areas can improve accessibility [42]. For secondary hospitals, it is advisable that the grade of existing hospitals should be improved. For primary hospitals, the government should increase financial investment and build primary hospitals in areas with low accessibility of TS and YJ. For health centers, although the number of health centers is more than that of general hospitals, and nearly 90% residential areas can access the nearest health center within 15min, but the accessibility scores of health centers are low, implying that the medical services provided by health centers cannot satisfy the demand of local residents. The government should take full advantage of the close proximity of health centers, transfer quality medical resources from high-grade hospitals to health centers, and strengthen the service capacity of health centers [43]. Last and most important point, the government should further promote the “graded diagnosis and treatment” policy, improve the medical insurance reimbursement system to fundamentally solve the problem of medical treatment for residents.

**Limitations**

The results of this study are helpful to understand the allocation of medical resources in Wenzhou, and provide a basis for the relevant departments to formulate reasonable planning and layout. However, this study has several limitations that we hope to improve in the future studies. Frist, due to the data limitation, the population data is at subdistrict/town level, and the location of residential areas is not accurately located, which affects the accuracy of the accessibility score. Second: The influence of demographic factors on accessibility is not considered. Finally: Only the number of doctors represents the service capacity of the medical institutions, without considering the subjective preferences of residents to obtain medical treatment.

The unreasonable spatial distribution of medical resources in cities, represented by Wenzhou, reflects the existing problem of supporting public service in Chinese cities. The methods also can be applied to other public services in other countries and regions, especially regions with obvious heterogeneity in public services resources, which has important policy guiding significance[44]. Future work should comprehensively consider more dimensions of spatial accessibility, such as population, socio-economic and culture barriers, to enhance the accuracy of accessibility.

**Conclusions**
In this research, the health economics and the modified H2SFCA method were applied to evaluate the equality of medical resources distribution and the accessibility of different levels of medical institutions, respectively. And the influencing factors of accessibility difference was explored by spearman correlation analysis. According to the results, the following conclusions can be drawn: (1) The distribution of medical resources in Wenzhou is unbalanced, and the medical resources in LC are highly concentrated, while WC, TS and DT are relatively short. (2) The distribution of medical resources in Wenzhou is inequitable according to population and geographical distribution. (3) The overall spatial accessibility of Wenzhou is poor; the accessibility of east regions is higher than west regions, and there are obvious differences in accessibility of hierarchical medical institutions. (4) Accessibility is positively correlated with the number of institutions, the number of doctors, population density, road density and GDP. Therefore, when making health planning, the government should take population and geographical factors into consideration to narrow the regional differences and improve the efficiency of medical resource allocation. Moreover, the government should increase financial investment in economically backward areas, strengthen the construction of hospitals, and improve traffic conditions to meet the demand of local residents for medical treatment.

Abbreviations

2SFCA: two-step floating catchment area; H2SFCA: hierarchical two-step floating catchment area

Declarations

Ethics approval and consent to participate

Not applicable

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analysed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests

Funding

Not applicable

Authors’ contributions

MD, TF and KM contributed to the framework and designed of this study. MD, LYF and YHZ provided assistance in data collection. MD wrote the first draft with supervision from KM. HH and MHZ helped revising the draft. All authors contributed significant intellectual content in this study and approved the final submission.

Acknowledgements

Not applicable

References


**Figures**

![Figure 1](image)

The distribution of medical institutions in the study area.
Figure 2

The travel time cost to nearest medical institutions.
Figure 3

The spatial accessibility of (a) all medical institutions, (b) tertiary hospitals, (c) secondary hospitals, (d) primary hospitals, and (e) health centers.
Figure 4

Proportions of residential area and population under different grades of hospital accessibility