A GIS-based method to assess the shortage areas of community health service

--- Case study in Wuhan, China

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***Abstract*—One of the major issues needed to be addressed in health sector in China is that low accessibility caused by inequitable resource allocation rather than resource deficiency. Health care facility planners and policy makers need accurate and reliable measures of accessibility as a planning support or the first step of essential policy intervention. In this paper, the enhanced two-step floating catchment area (E2SFCA) method was applied for the community health system of Wuhan. The sensitive analysis was carried out on different distance decay weights. As the finding of the research, the shortage areas of community health service in Wuhan were identified and suggestions were made on how to alleviate the community health care deficiency.**

Keywords-community health care; E2SFCA; spatial accessibility; GIS

I. INTRODUCTION

One of the main goals for health care facility planning is to achieve the equitable geographic distribution of health care resources. An equitable distribution of health care resources can achieve two main goals set for facility planning: (1) cost containment by decreasing oversupply and (2) equity of access by increasing supply to underserved areas[1]. In addition, equitable geographic distribution of health care resources is a component of social justice in health sector which is vital for a harmonious society.

However, because there has been an overwhelming concern about the affordability of care as well as a neglect of spatial accessibility (SA) of health care facilities which is an important component of border concept of access, the underserved areas are not well identified[2]. As reported by World Health Organization, “One of the main problems with urban health care is not simply that it lacks quality and comprehensiveness but that, because of misdistribution of facilities, it is often not easily accessible to those in need” [3].

In 2005, the Government of Wuhan invested 43 million RMB in establishing community health facilities to provide primary health care for Wuhan citizens within a 15 minute walk. With the accelerating rate of urbanization and urban expansion, health provision in Wuhan is confronted with an increased demand but a shortage of medical service. Health planners and policy makers need accurate and reliable measures of accessibility so that shortage areas can be accurately identified and resources can be allocated to the neediest areas to alleviate the problem.

II. METHODS

Traditional methods to measure spatial accessibility to health care includes provider-to-population ratios, travel impedance to nearest provider, average travel impedance to provider and gravity models. In this research, the enhanced two-step floating catchment area (E2SFCA) method is implemented for the case study of Wuhan.

The two-step floating catchment area method (2SFCA), first proposed by Radke and Mu[4] but later modified by Luo and Wang[5], is a special case of gravity model. It not only has most of the advantages of a gravity model, but is also intuitive to interpret, as it uses essentially a special form of physician-to-population ratio[6]. The method is implemented in the following two steps:

Step 1: For each physician location j, search all population locations (k) that are within a threshold travel time (d_0) from location j (this is the catchment of physician location j or catchment j), and compute the physician-to-population ratio, R_j, within the catchment area:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\le d_0\}} P_k} \quad (1)$$

Where P_k is the population at location k whose centroid falls within catchment j ($d_{kj} \le d_0$), S_j the number of physicians at location j, and d_{kj} the travel time between k and j.

Step 2: For each population location i, search all physician locations (j) that are within the threshold travel time (d_0) from location i (that is, catchment area i), and sum up the physician-to-population ratios (derived in step 1), R_j, at these locations:

$$A_i^F = \sum_{j\in\{d_{ij}\le d_0\}} R_j = \sum_{j\in\{d_{ij}\le d_0\}} \frac{S_j}{\sum_{k\in\{d_{ij}\le d_0\}} P_k} \quad (2)$$

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Where A_i^F represents the accessibility of population at location i to physicians based on the two-step floating catchment area method, R_j is the physician-to-population ratio at physician location j whose centroid falls within the catchment centered at population location i ($d_{kj} \le d_0$), and d_{ij} the travel time between i and j. A larger value of A_i^F indicates a better access to physicians at that population location. The first step assigns an initial ratio to each catchment (or service area) centered at physician locations, and the second step sums up the initial ratios in the overlapping service areas where residents have access to multiple physician locations.

However, the 2SFCA method has two limitations[5]: (1) it is a dichotomous measure i.e., all locations outside of the catchment have no access at all and (2) it does not differentiate distance impedance within the catchment i.e. all population locations within the catchment are assumed to have equal access to physicians. Luo[6] worked on the limitation and mentioned an enhanced two-step floating catchment area (E2SFCA) method lately. In order to differentiate accessibility within a catchment, multiple travel time zones within each catchment are obtained using ArcGIS Network Analyst and assigned with different weights according to the Gaussian function. The Eq. (1) was transformed as below:

$$R_j = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_r\}} P_k W_r} = \frac{S_j}{\sum_{k\in\{d_{kj}\in D_1\}} P_k W_1 + \sum_{k\in\{d_{kj}\in D_2\}} P_k W_2 + \sum_{k\in\{d_{kj}\in D_3\}} P_k W_3} \quad (3)$$

And the Eq. (2) was transformed as below:

$$A_i^F = \sum_{j\in\{d_{ij}\in D_r\}} R_j W_r = \sum_{j\in\{d_{ij}\in D_1\}} R_j W_1 + \sum_{j\in\{d_{ij}\in D_2\}} R_j W_2 + \sum_{j\in\{d_{ij}\in D_3\}} R_j W_3 \quad (4)$$

The consideration of distance decay (by travel time zones) in the E2SFCA method is a reasonable approximation to the continuous gravity model. This approximation makes the result of the 2SFCA method straightforward to interpret and easy to use, because it is essentially a weighted physician-to-population ratio. With the advances in GIS technology and availability of street network data, the E2SFCA method can be easily implemented with GIS software.

III. CASE STUDY IN WUHAN, CHINA

A. Study area and data source

In this study, the study area is emphasized on the central districts of Wuhan which are consisting of seven districts: Jiang An, Qiao Kou, Jiang Han, Han Yang, Qing Shan, Wu Chang and Hong Shan. Table 1 presents the data sources of the analysis.

There are three categories of community health care facilities: the Community Health Center (CHC), the Community Health Station (CHS) and the Village Health Center (VHC). According to the administrative organization of Wuhan, communities are applied for urban areas while villages are for rural areas. The CHCs and CHSs cooperatively cover the primary health care in the urban areas and the VHCs cover the primary health care in the rural areas. The CHCs has the highest medical level and authorities in the Community Health Care System and provide beds, while no bed is provided for the CHSs and VHCs. Moreover, one CHC is responsible to assist and supervise the health provision of several CHSs.

TABLE 1. DATA SOURCE

Data	Source	Description
Population	Wuhan Statistical Bureau	Available on street level; no population distribution data
Administrative Boundaries	Wuhan Urban Planning Bureau, Information Center	Total 1052 communities and villages for the 7 central districts
Road Networks	Wuhan Urban Planning Bureau, Information Center	Four hierarchies: major road; secondary road; urban feeder road; rural feeder road
Community Health Facilities	Wuhan Hygiene Bureau	116 Community Health Centers (CHC); 367 Community Health Stations (CHS); 160 Village Health Centers (VHC)

B. Data process and parameters setting

1) Data process

Since the population distribution data is unavailable, it is assumed that the population density is uniform within every neigbourhood. In this research, the study area was subdivided into a square tessellation of 500*500 meter cells (i.e. a cell cover an area of 0.25 km2). The geographic centroid of each cell (census point) is counted as the population location (demand location) for health care. A total of 2908 census tract centroids cover the study area. By the E2SFCA method, census tracts are scored to illustrate the spatial accessibility from these areas to community health facilities.

2) Parameters setting

Because the major responsibility of the community health services is to provide primary health care to families on the community level, most patients would choose to walk to the nearest CHC, CHS or VHC. It is assumed that people pick the nearest route when walking (walk speed: 5km/h). The Network analysis is carried out to find suitable parameters for travel impedance (see Fig. 2).

Figure 1. Walk time distributions

Most health facilities could be easily reached within a walk time of 10 min or 20 min in the urban areas as shown in Fig.1. However, primary health care is unreachable even within a walk time of 30 min in some suburban and rural areas due to the lack of a well developed network and the more sparsely located facilities. Thus, an undeveloped road network implies more walk time for health seeking behavior. According to the policy goal of covering all the communities within 15 min walk catchment area, three walk time zones are set for the study: 0min – 15min, 15min – 25min, 25min – 35min.

As for the E2SFCA method, the weight W_r for different travel time zone reflects the distance decay (see Eq. (3), Eq. (4)). Adapted from the research of Wei Luo[6] who proposed the E2SFCA method, two sets of weights are used in the E2SFCA method: weight set 1 (=1.00, 0.68 and 0.22 for the three travel time zones) represents slower distance decay; weight set 2 (= 1.00, 0.42 and 0.09) represents sharper distance decay.

C. Procedure of the enhanced two-step floating catchment area (E2SFCA) method

The flow chart of the enhanced two-step floating catchment area method (E2SFCA) is briefly illustrated step by step as shown in Fig. 2.

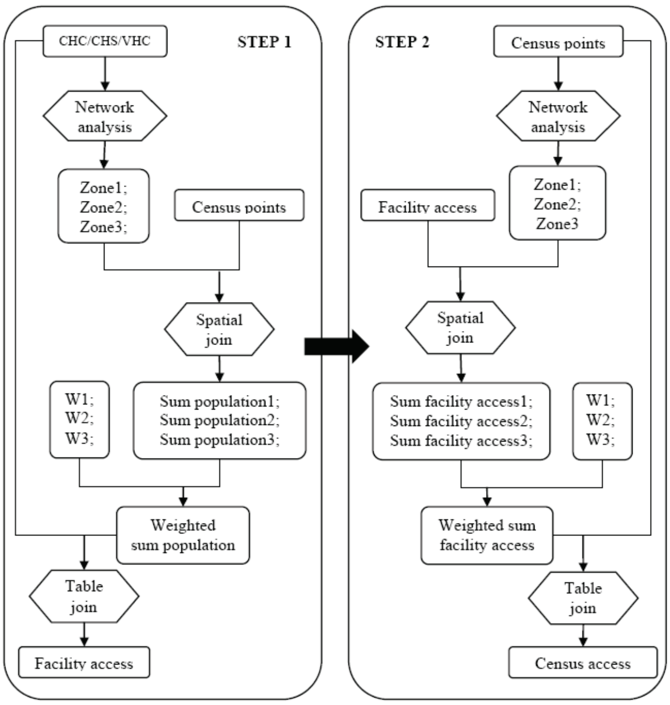

Figure 2. Flow chart of E2SFCA method

In the first step, three travel time zones away from the community health care facilities which was 0-15min, 15-25min and 25-35min in this case study are calculated by the Service Area Tool of Network Analyst. The population that falls inside each travel time zone is multiplied by distance decay weight and summed up. Beds/10^4 persons (or physicians/10^4 persons) to population ratios are calculated as facility access which means that every community health care facility gets one value.

In the second step, the same three travel time zones away from census points are calculated in the Network Analysis. For each travel time zone, the access of community health care facilities that fall inside is weighted and summed up as census access which is the spatial accessibility of each census points (population location). As a sensitivity analysis to the E2SFCA method, different distance decay, W_a and W_b, are applied into the case study.

D. Results and discussions

The result from applying E2SFCA (W_a=1.00, 0.68, 0.22) for the Community Health Care System is presented in the Fig.3. The result shows that the high accessibility areas are located in the suburban and rural areas with lower population density instead of in the city center. It is also indicated that road networks have more remarkable impact on the spatial accessibility of the hospitals in rural areas, although there are less options of health care facilities.

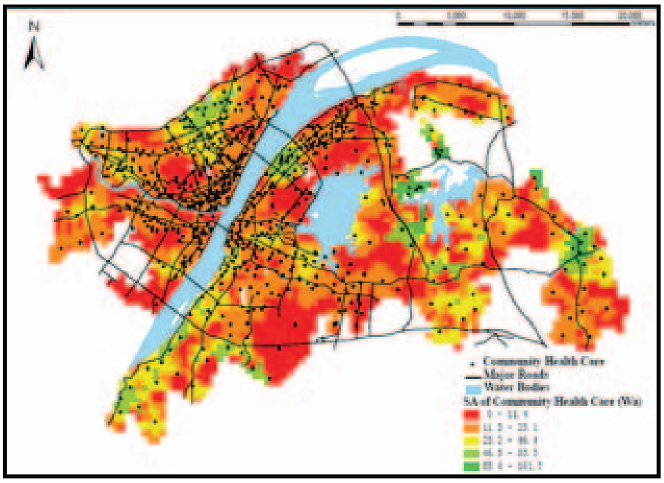

Figure 3. Spatial accessibility of the Community Health Care System (Wa)

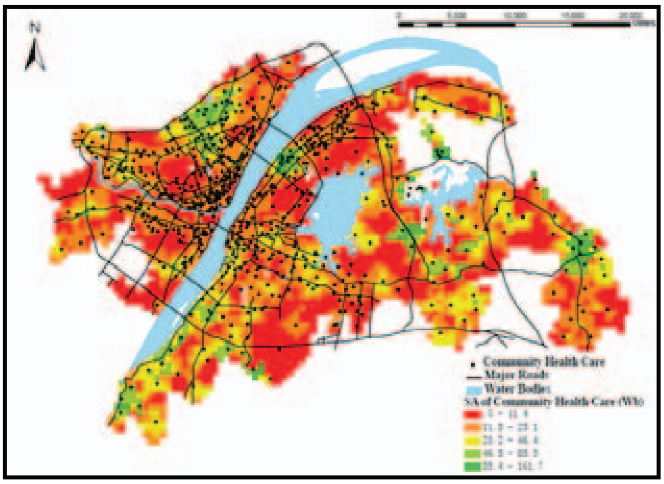

Figure 4. Spatial accessibility of the Community Health Care System (Wb)

The result from applying the E2SFCA method with the distance decay weight W_b (= 1.00, 0.42, 0.09) which indicates shaper distance decay as shown in Fig. 4. The result of Wb shows the similar SA pattern as the W_a. However, the latter tends to stress the affection of distance decay more than W_a by determining more areas with highest value and lowest value at the same time. In other words, a sharper distance decay weight is inclined to sharpen the SA results by increasing the optimum values. The finding reveals that the setting of weight is an important determinant of spatial accessibility for the E2SFCA method. In practice, various distance decay weight could be used to reflect the characteristics of health provision (e.g. primary health care shows a sharper decay and serious disease treatment shows a slower decay).

IV. CONCLUSIONS

Based on the previous discussion, the results of the sharper distance decay W_b is adopted for assess the shortage areas of Community Health Service considering its function of providing primary health care.

Most of the health deficient areas locate on the periphery of the study areas where scarce facilities are located in as shown in Fig. 5. Most of the communities locate in the Hong Shan district which owns vast rural lands as shown in Table 2. However, there are still some communities locate in the urban areas like Qiao Kou, Jiang Han and Han Yang districts.

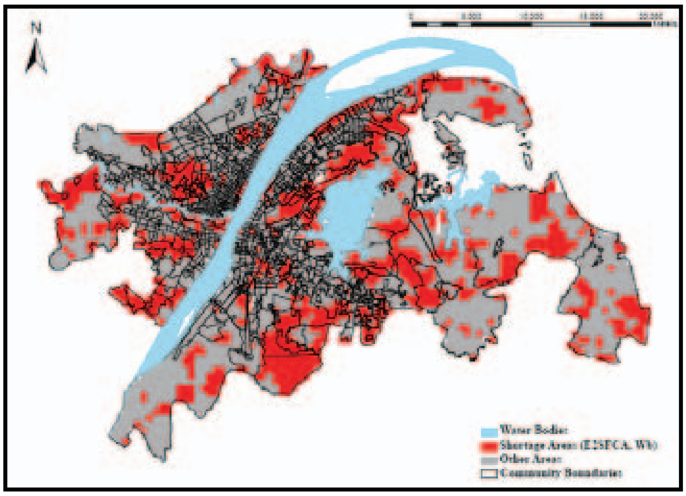

Figure 5. Shortage Areas of the Community Health Service

The service radius of the community health facilities, which is decided by their capacity (number of beds or physicians), is more or less on the same level. Therefore, the location of facilities is the most important determinant of spatial accessibility. The best way to alleviate the shortage for the Community Health Care System in Wuhan is to establish more facilities in the deficient areas, which is feasible because of the comparatively lower requirements on medical appliances and medical staffs.

In conclusions, the E2SFCA method is easy to implement and straightforward to interpret with the Network Analyst in ArcGIS and low data requirement. The method is an accurate and reliable measure tool of health accessibility for health care facility planners and policy makers to identify deficient areas and allocate scarce resources to those needy areas. The findings in the case study of Wuhan are representative and the method could be easily applied for other cities in China and in any other countries around the world.

TABLE 2. MAJOR COMMUNITIES IN HEALTH PROVISION SHORTAGE

Communities in shortage	**District name**	**Shortage Area(km^2)**	**Population in shortage**
Luo Nan	Hong Shan	4.8	45972
Ji Chang	Jiang Han	2.8	26713
Luo Shi	Hong Shan	2.5	14079
Hua Shan	Hong Shan	23.5	11621
Gong Ren	Qing Shan	3.5	11125
Hong Shan	Hong Shan	5.3	10543
Zuo Lin	Hong Shan	16.8	9958
Yong Feng	Han Yang	13.0	8028
He Ping	Hong Shan	11.0	7706
Jian She	Hong Shan	9.0	5798
Jiu Feng	Hong Shan	14.0	4901
Qing Lin	Hong Shan	12.0	4349
Jiang Ti	Han Yang	3.0	2566
Chang Feng	Qiao Kou	3.3	2401

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