Development of a hexagonal, mesh-based distribution method for community health centres

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Abstract

Community health centres (CHCs) are the *health gatekeepers* of the local population. Location and numbers of the CHCs affect fairness and effectiveness with regard to access to primary health care. In the past, the distribution of the CHCs was solely empiric-based. The goal of this study was to devise a method for CHC distribution based on the principle of improving equity as well as ensuring efficiency. We tested the effectiveness and operability of the method through a process of revision and simulation using Guangdong Province, China as sample district. A methodology based on literature review and expert consultation was repeatedly applied until an ideal result had been reached. A hexagonal, mesh-based method was developed and used to find a solution where the CHCs could be distributed where their location would be the most needed and total number suitable. Testing the effectiveness of the proposed plan, we found the proportion of area covered to be 52.8% and the proportion of the population covered 80.7%, which is 15.4% and 14.7%, respectively, better than before. It was concluded that the hexagonal mesh-based, distribution method can effectively define the location as well as the number or required CHCs, not only improving the accessibility for residents to primary health care services but also maximizing cost-effectiveness. Management of the city by grid is a new idea in urban management, which improves rationality of planning and also may be applied for many different purposes in addition to CHC localization.

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Introduction

Community Health Centres (CHCs) represent the most prevalent community-level form of healthcare connection available to the general public. They are the first point of contact between the family/community and the national health system bringing health care as close as possible to where people live and work. Although the World Health Organization (WHO) put forward the slogan *Health for All by 2000* in the Declaration of Alma-Ata 1978, (WHO, 1978), seven out of 10 CHC patients in North America still live in poverty, and well over half are members of minority groups (Adashi *et al*., 2010). These authors also point out that the CHC is often the sole health care provider available to these patients. CHC planning is therefore critical to achieve full health coverage for all people. However, there are relatively few studies on CHCs distribution. In the past, planning was often done empirically or by using administrative divisions. Access to primary health care varies from one area to another because health services are affected by the location (supply) of the CHC and patient residence location (demand), and neither health professionals nor populations are uniformly distributed.

In order to achieve the goal of primary health care for everyone, it is important to establish the proper location and capacity of available CHCs. Recently, geographical information systems (GIS) and related spatial techniques have been used for analyzing the relationship between health outcomes and accessibility, as well as better health services (Moore and Carpenter 1999; Bell *et al*., 2006; Sasaki *et al*., 2008; Lee, 2013). In the context of current and future public health needs, it is possible to analyze the role of supporting public health programmes, such as maximizing resource efficiency (Luo and Wang, 2003; Sasaki *et al*., 2010). To identify areas where it would be useful to locate CHCs, researchers aggregate the city into accessibility zones, and planners use the zones to decide whether currently available health facilities cover the entire city or not. This method is useful for the evaluation (Luo and Wang, 2003), as the areas uncovered by CHCs are clearly visualized. However, the approach leads only to the identification of approximate areas that should benefit by an additional CHCs, so the question of exact numbers and locations of CHCs to be added without duplication or omission remains partly unsolved. In addition, the cost-effectiveness of adding new CHCs is low in areas with low populations, since maintenance of operations requires a certain minimum number of people.

The goal of this study, based on the principle of improving equity as well as ensuring efficiency, was to develop a method of assessing which areas require new CHC and if so where to localize them. Cost-effectiveness and accessibility should be maximized with a minimum increase of the number of CHCs.

Materials and Methods

Increasing equity does not entail sacrificing efficiency, *e.g.*, if the number of CHCs were significantly increased, equity would certainly be improved, but cost-effectiveness might decrease. We propose instead to maximize accessibility to primary health care for all residents in a way that also makes sense financially.

Literature review

In order to solve these problems encountered with regard to CHC localization, we conducted a literature review. Taking *accessibility/spatial accessibility* as the key word, we searched China National Knowledge Infrastructure, the PubMed, the Web of Knowledge databases. After screening, a total of 170 papers were obtained. 64 articles related to the *spatial accessibility evaluation method*, 11 to *process analysis*, 39 to *index construction*, 56 to topics of visual expression (including 6 articles referring to *spatial location determination*), 19 to *road network distance calculation*, 23 to *Population spatial distribution simulation* and 8 to the *grid data model*. This literature search contributed considerably in providing both a theoretical and a methodological basis for this study.

Expert consultations

We also engaged in consultation with experts. These experts included individuals in charge of CHCs, health bureau staff, school teachers and experts in health planning. After comparing the difference between theoretical results and actual experience, we adjusted and perfected our method recursively. Finally, we established a method for estimating the best distribution of CHCs based on a hexagonal mesh. The roadmap for establishment of the methodology is shown schematically in Figure 1.

Data simulation

In order to test the operability and validity of the method, we selected a sample district in Guangdong Province, China as an example. We have previously applied this method to make policy recommendations for the rational distribution of community health service stations for other areas, such as Songjiang and Hongkou districts in Shanghai and also to Jinjiang District of Fujian Province, which indicated that this method could be generalized. Our aim now was to demonstrate the usefulness of the approach in one specific district in Guangdong Province. Table 1 displays the list at the county level of data and sources corresponding to our research.

Software

Primary data organization and analysis were performed using Microsoft Excel, 2013.

Mapping and calculation of spatial analysis were performed using ArcGIS v10.1 by ESRI (Redlands, CA, USA).

The community health centres distribution plan

In order to achieve the goal of full coverage, the number of CHCs in underserved areas would need to increase. Our strategy was to divide the region using a grid, counting the number of CHCs and the number of people in each cell of the area, then determining the location and number of CHCs needed for full coverage.

Theoretical fundament

A CHC service area can be described as an area with the CHC near the centre. Its shape would ideally be a circle, but geographical areas cannot be seamlessly apportioned in that way (Figure 2), so we decided to introduce the hexagonal form. The hexagon approximates the circular ideal of a service coverage area, while at the same time satisfying both the demands of comprehensiveness and the absence of overlap, thus avoiding duplication or omission of any services (Figure 2). Importantly, hexagons, like squares and like-sided triangles, can easily be laid out side by side without running into the tiling problem where angels do not fit.

The *radius* of each hexagon determines the maximum walking distance to a CHC from people's homes. According to WHO's requirement for developing countries, the range of a CHC service area should be within 15 minutes on foot. According to expert consultation, we set the average walking time as 100 m per minute, making 1,500 m the chosen *radius* of each hexagon as seen in Figure 2.

With at least one CHC in each hexagon, full coverage in a given area can be ensured. However, the number of CHCs also depends on the population. If its density would be very high in an area, one CHC might not be capable to fully meet the needs of the residents there. Conversely, if the population base would be very low, the cost-effectiveness of adding CHCs would also be low. Thus, we needed to develop a criterion for adjusting CHC numbers based on geography as well as population. According to the existing situation and expert consultation, we decided that the greatest number of people to be served by one CHC should be approximately 10,000, while the lowest should be somewhere around

Table 1. Overview of data acquired.

Category	Type of information	Level	Source	Date
Population data	Distribution of people in 267 villages	County	Health Bureau	November 2016
Geographic data	Digital maps	County	Bureau for urban planning and design	December2015
	Digital map of road network	County	Bureau for urban planning and design	December2015
CHC	CHC distribution	County	Health Bureau	August 2016

CHC, community health centres.

5,000. For areas in which the population was low or varied between 5,000 and 10,000, the hexagons were merged until the population reached 10,000. Additionally, areas with an insufficient number of CHCs in relation to the population would receive one CHC for each additional 10,000 population, while no CHC was added to areas with less than 5,000 people. The criteria for adding CHCs are displayed in Table 2.

Empirical approach

We conducted a simulation in the sample district in Guangdong Province. Based on the 15-minute access requirement, the area was divided by means of GIS software into 392 CHC service areas, each represented by a hexagon (Figure 3).

To determine the appropriate number and location of CHCs, we first summarized the number of CHCs in each hexagon and then located the areas without CHCs. There were 249 hexagons without CHCs (Table 3, Figure 4). These non-CHC areas, amounting to 63.5% of the total number, were considered priority localizations for additional CHCs.

Evaluation

Accessibility can be implemented based on spatial and non-

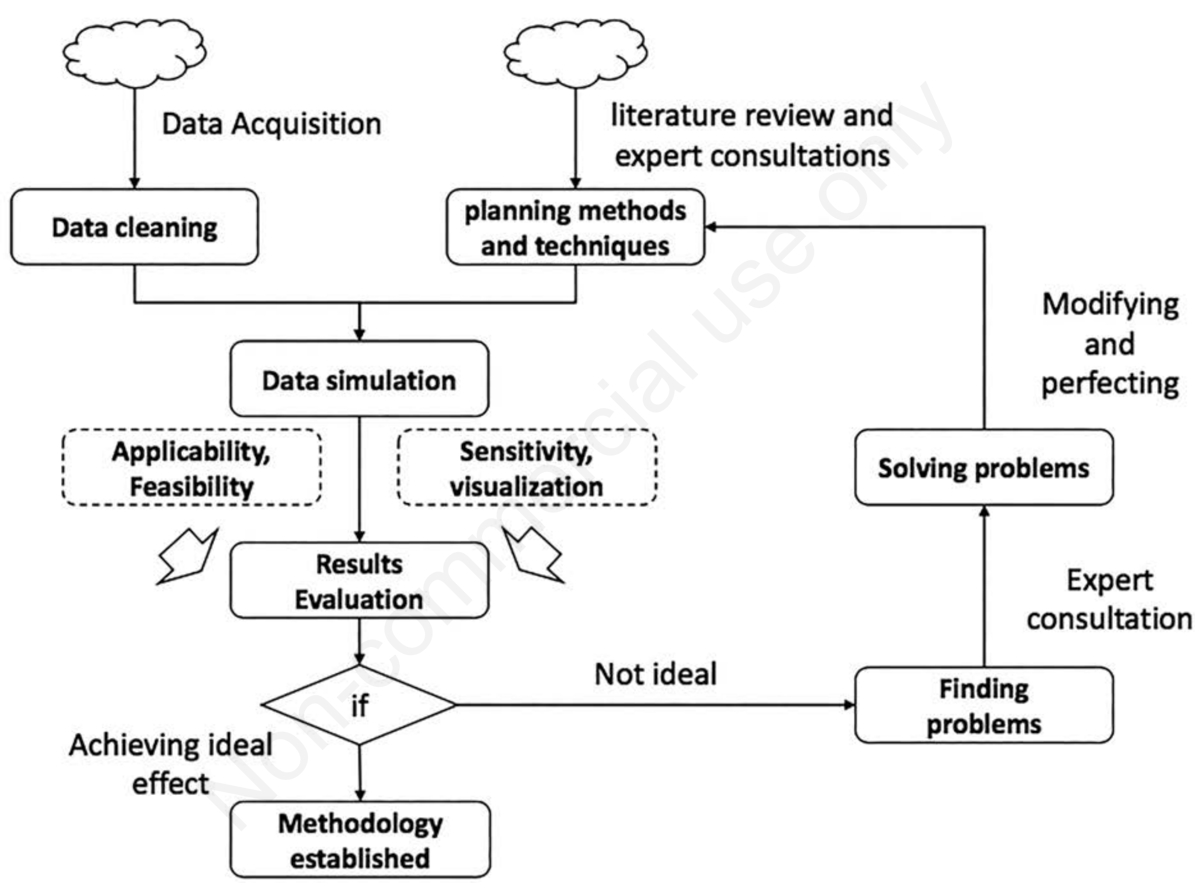

Figure 1. Technical roadmap for establishing the methodology.

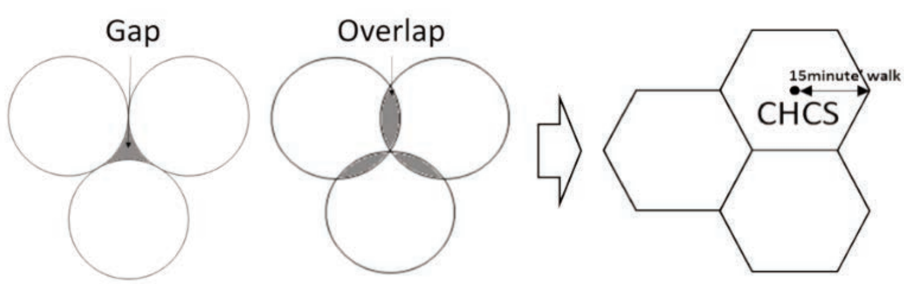

Figure 2. Graphical representation of service areas and the range of each hexagonal grid. CHC, community health centres.

spatial factors (Murad, 2007). According to the purpose of this study, we only considered the spatial accessibility, *i.e.* the provider-to-population ratio. The accessibility of health services should be an important indicator to evaluate the methodological effectiveness.

The actual service area was used to measure the range of CHCs providing primary health care to residents. This area has the CHC near the centre, and 15-minute walk's distance is used as the distance limit. To reflect the effectiveness of CHC distribution, we used two indices when estimating the CHC service area: the proportion of area coverage, and the proportion of population coverage (Zhou *et al.*, 2016).

Results

We summed the number of people in each hexagon, and calculated the number of CHCs needed. Together, there were 117,751 people (42.0% of the total population) in the non-CHC areas. Out of the 249 non-CHC hexagons, 170 hexagons had populations lower than 5,000, 57 hexagons had populations between 5,000 and 10,000, while 27 hexagons had populations of between 10,000 and 20,000. Our proposal entails not adding any CHCs in lowest populated areas as it would not be cost-effective, while adding 22

Table 2. Criteria for community health centre (CHC) adjustment.

Category	Population	Proposal
Areas without CHCs	≤ 5000	No CHC addition
	5,000-10,000	Add CHC after area combination
	10,000-20,000	Add one or two CHC(s)
Areas with CHCs	≥10,000	Add one CHC for each additional 10,000 population

Table 3. CHC distribution.

Number of CHCs in each hexagon	Number of hexagons
0	249
1	107
2	27
3	6
4	1
5	1
6	1
Total	392

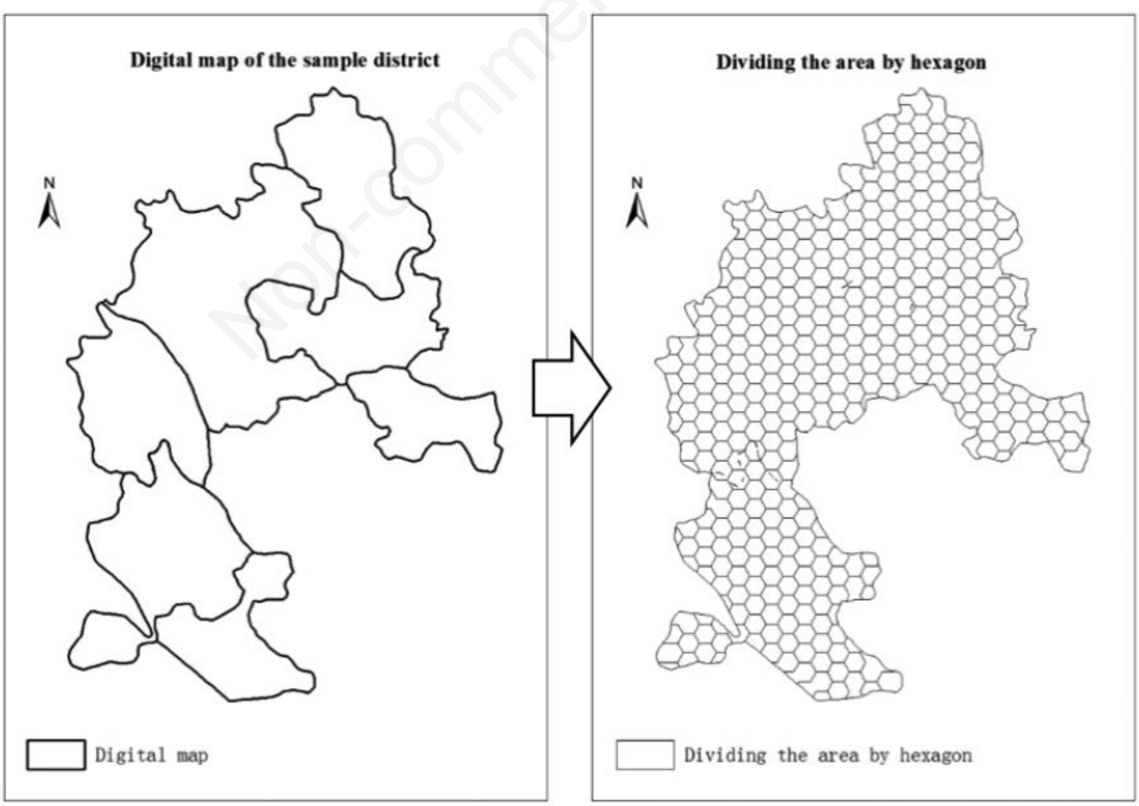

Figure 3. The sample area in Guangdong and its division into hexagons.

CHCs to the 57 moderately populated hexagons after merging some of them. For the areas covered by the 27 hexagons with high populations, 27 CHCs should be added. (Table 4, Figure 4).

Out of the hexagons that already had a CHC, one had between 20,000 and 30,000 people, a situation requiring an estimated two more CHCs according to our calculations. Eight hexagons with populations between 10,000 and 20,000, would each need an additional CHC, *i.e.* eight CHCs in all (Table 4, Figure 4).

After planning, the proportion of area coverage of CHCs service area was 52.8%, which is 15.4% higher than before. The ratio of population coverage was 80.7%, which is 14.7% higher than before (Table 5, Figure 5).

Discussion and Conclusions

A hexagonal, mesh-based distribution method can effectively define the location and number of needed CHCs with maximum cost-effectiveness. Maximum accessibility is achieved, while a minimum of CHCs need to be added. The hexagonal grid division avoids all duplication or omission of coverage, and all people in each hexagon are guaranteed health support. This method thus achieves the planning objectives to improve equity as well as to ensure efficiency, and CHCs are added to the areas most in need. In consequence, not only will geographical accessibility to primary health care services be strengthened, but by taking the variation of population in each area, crowding, as well as under utilization, are avoided at each CHC, which is the key factor to maintain operation.

Table 4. Current population distribution and estimated CHC requirement.

Category	Population	Number of hexagons	Additional CHCs required
Areas without CHCs	≤ 5000	170	0
	5000-10000	52	22
	10000-20000	27	27
Areas with CHCs	10000-20000	8	8
	20000-30000	1	2

Table 5. Evaluation of the distribution plan effect.

Category	Before planning	After planning	Increase
Proportion of area coverage	43.5%	52.8%	9.3%
Proportion of population coverage	66.0%	80.7%	14.7%

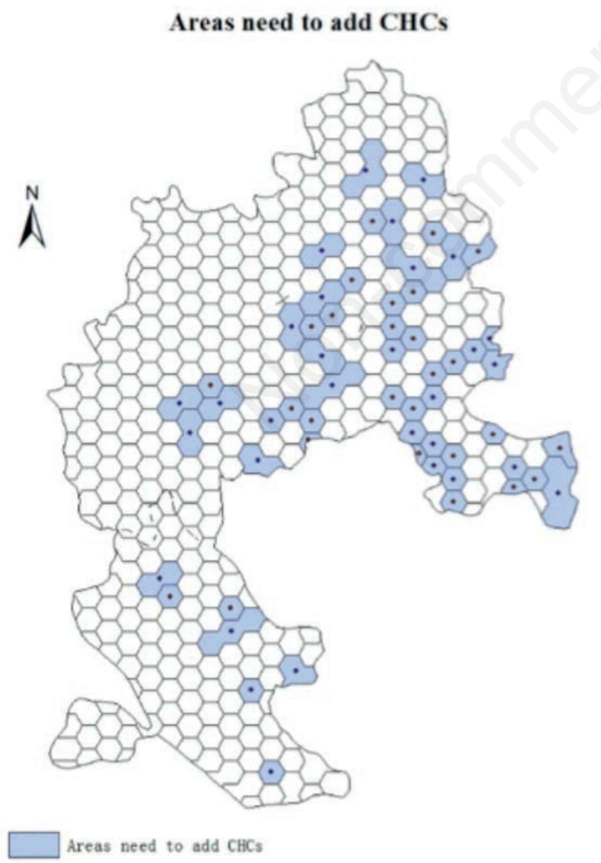

Figure 4. Areas where community health centres (CHC) should be added. A dot represents one CHC.

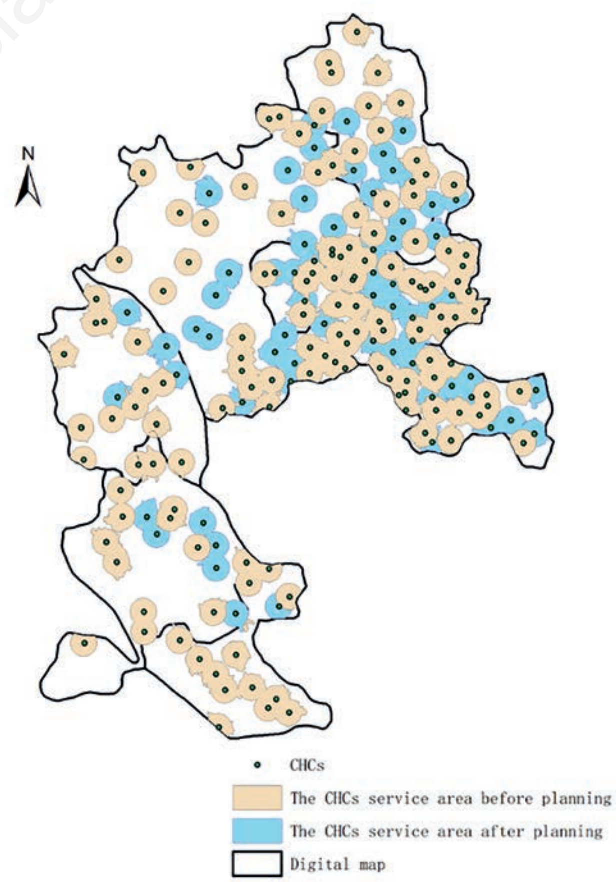

Figure 5. Effect of the distribution plan.

At present, urban management by grid has become a new idea in urban management. How to provide citizens with more convenient public management and public services are among the most prominent problems faced by city governments in modern cities. Establishment of new methods of urban management is urgent.

Visual expression makes the method easily understood and accepted. Indeed, mapping is an excellent means of communicating a message clearly even to those who are not necessarily familiar with the methodology. Visualization of CHCs allows abstract concepts to be translated into intuitive, understandable graphics that convey scientific research conclusions to decision makers in a concise and understandable way, enabling them to quickly understand and adopt.

The reliability and validity are the criteria used to evaluate the quality of the method. Reliability can be guaranteed by consistency and stability of the method. The consistence and stability of basic data are guaranteed by the standard type, formulation and sources, and the consistence and stability of calculation process and result are guaranteed by the standard methodology to deal with data and visualize the results. The validity of the method is ensured by the actual increase in accessibility of residents to primary health care shown here and also judged by experts.

The fact that location of the grids may affect the result slightly is a limitation of the work since moving the grids would change the number of population and the number of CHCs counted. However, we have done relevant studies to examine the effect of different grid positions on the final results, which shows that it only has a marginal effect. In addition, no matter which grid the CHCs and population are in, the purpose of our study is to find out the areas where supply and demand do not match.

Although we only considered spatial accessibility, we understand that the health needs are also related to other factors, *e.g.*, the proportion of elderly population, the level of economic development and so on. As it will affect the number of CHCs needed, we plan to improve our methodology by also take these factors into account in future studies.

This paper is a methodological study with a focus on health care, but urban grid division applied in this paper can be generalized. Thus, the approach proposed can not only be used for the localization of CHCs, but also for other fixed structures in the built environment, *e.g.*, pharmacies, convenience stores, *etc*. It would only be needed to define the size of each grid based on the particular purpose chosen.

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