Health & Place 18 (2012) 789–795

Contents lists available at SciVerse ScienceDirect

Health & Place

journal homepage: www.elsevier.com/locate/healthplace

Variable catchment sizes for the two-step floating catchment area (2SFCA) method

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ARTICLE INFO

Article history:
Received 2 December 2011
Received in revised form
30 March 2012
Accepted 9 April 2012
Available online 22 April 2012

Keywords:
Potential spatial accessibility
Two-step floating catchment area method
Variable catchment size
GIS
Primary care physician

ABSTRACT

Government efforts designed to help improve healthcare access rely on accurate measures of accessibility so that resources can be allocated to truly needy areas. In order to capture the interaction between physicians and populations, various access measures have been utilized, including the popular two-step floating catchment area (2SFCA) method. However, despite the many advantages of 2SFCA, the problems associated with using fixed catchment sizes have not been satisfactorily addressed. We propose a new method to dynamically determine physician and population catchment sizes by incrementally increasing the catchment until a base population and a physician-to-population ratio are met. Preliminary application to the ten-county region in northern Illinois has demonstrated that the new method is effective in determining the appropriate catchment sizes across the urban to suburban/rural continuum and has revealed greater detail in spatial variation of accessibility compared to results using fixed catchment sizes.

1. Introduction

Despite its large per capita health expenditure, the U.S. falls behind other industrialized nations in key health performance measures (http://www.who.int/whr/2000/en/index.html). One of the primary reasons for this gap is the large disparities in both access to care and health outcomes. Access to primary healthcare is recognized as an important facilitator of overall population health and has remained a major goal of U.S. health legislation and government initiatives in past years. Access to healthcare (or healthcare accessibility) refers to the relative ease by which healthcare can be reached from a given location (Wang, in press) and is influenced by many factors, e.g., the supply of health services and physicians, the demand of patients (population) seeking care, the socio-economic and financial resources available to patients, and geographical impedance between patients and doctors (Aday and Andersen, 1974). Depending on whether the emphasis is on actual healthcare utilization versus service availability, or on spatial factors (such as geographic barriers) versus nonspatial factors (such as insurance), healthcare accessibility can be divided into four categories: potential spatial accessibility, potential non-spatial accessibility, revealed spatial accessibility, revealed non-spatial accessibility (Khan, 1992). The focus of this paper will be on potential spatial accessibility measures and on demonstrating a new methodology.

Potential spatial access to medical services is primarily dependent on three factors: supply of medical services/physicians, population demand for the services, and travel costs between the demanding populations and medical sites (Wan et al., 2011). Various measures of spatial accessibility have been proposed, including regional availability (Khan, 1992), the gravity model (Joseph and Bantock, 1982) and the two-step floating catchment area (2SFCA) method (Luo and Wang, 2003). Of these methods, the regional availability method is the simplest to compute, as it is simply the ratio of supply (doctors) and demand (population) within a predefined area (e.g., administrative boundary). However regional availability measures do not reveal the spatial variation within the boundary, nor do they account for the interaction between supply and demand across the boundary. The gravity model is theoretically more sound, but it requires more computation and the result is not intuitive to interpret (Joseph and Phillips, 1984). The gravity model often takes the following form (Luo and Wang, 2003):

$$A_i^G = \sum_{j=1}^{n} \frac{S_j d_{ij}^{-\beta}}{\sum_{k=1}^{m} P_k d_{kj}^{-\beta}} \quad (1)$$

A_i^G is the gravity-based accessibility at population location i, where n and m are the total numbers of physician locations and population locations respectively. P_k is the population at location k, S_j the number of physicians at location j, and d_{kj} (or d_{ij}) the travel time between k and j (or i and j). The denominator term

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http://dx.doi.org/10.1016/j.healthplace.2012.04.002

represents a measure of the availability of physicians at location j to all population (P_k, $k=1, 2, \ldots, m$). β is the friction-of-distance coefficient, which has to be determined by physician–patient interaction data and is often region specific (Huff, 2000). The difficulty in determining β limits the wide application of the gravity model.

The 2SFCA method is a special case of the gravity model and thus not only keeps most of the advantages of a gravity model, but is also intuitive to interpret, as it generates essentially a special form of physician-to-population ratio (Luo and Wang, 2003). It is easily implemented in a GIS environment using 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 forms the catchment of physician location j or catchment j), and compute the physician-to-population ratio, R_j, within the catchment area:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} P_k} \tag{2}$$

The variables are defined similarly as described above for the gravity model.

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:

$$A_i^F = \sum_{j \in \{d_{ij} \le d_0\}} R_j = \sum_{j \in \{d_{ij} \le d_0\}} \frac{S_j}{\sum_{k \in \{d_{kj} \le d_0\}} P_k} \tag{3}$$

where A_i^F represents the accessibility of population at location i to physicians based on the 2SFCA method. This is essentially a ratio of supply and demand and is thus straightforward to interpret.

The 2SFCA method has been used in a number of studies measuring healthcare accessibility (Yang et al., 2006; McGrail and Humphreys, 2009a,b; Dai, 2010; Schuurman et al., 2010; Dai, 2011; Dai and Wang, 2011; Ngui and Apparicio, 2011; Wan et al., 2011; Wang and Roisman, 2011). However, despite its relative popularity, at least three major limitations have been identified: (1) it is a dichotomous measure (i.e., all locations outside of the catchment are assumed to have no access at all); (2) it does not consider distance decay within catchments (i.e., all locations inside of the catchment are assumed to have equal access, Luo and Qi, 2009); (3) it uses fixed catchment sizes (d_0) for all physician (supply) and population (demand) locations, and thus does not correctly reflect the reality that people in rural areas are willing to travel further distances and longer times to seek care than those in urban areas (i.e., the catchments in urban and rural areas should have different sizes, (McGrail and Humphreys, 2009b)). Several studies have attempted to improve upon these limitations. For example, a kernel density function (Guagliardo, 2004) or a Gaussian function (Dai, 2010) has been introduced to account for the distance decay effect in a continuous fashion. Different weights for different travel time zones have also been used to model the distance decay effects in a step-wise discrete fashion (Luo and Qi, 2009). Yang et al. (2006) suggested varying the catchment size based on provider types or neighborhood types. McGrail and Humphreys (2009b) introduced a cap function to limit the size of the catchment in urban areas. However, the debates on what functional form to choose and what proper catchment size to use still remain (Wang, in press). Inspired by a method used for determining the proper area for computing cancer incidence rate (Tiwari and Rushton, 2005), this paper proposes a new method for determining the physician and population catchment sizes of the 2FSCA method by incrementally increasing the catchment until a base population (BP) and a physician-to-population ratio (PPR) criteria are met (hereafter referred as the Variable 2SFCA method or V2SFCA). Preliminary application of the V2SFCA method to a ten-county region of northern Illinois around the Chicago area has shown that it dynamically finds the appropriate catchment sizes across the urban to suburban/rural continuum and reveals more details of spatial variation in accessibility compared to the previous 2SFCA using fixed catchment sizes.

2. Methodology

The new V2SFCA method for determining the catchment sizes follows a similar two-step procedure as the original 2SFCA to take into consideration the spatial interaction between physicians and populations (see Fig. 1 for a flow diagram).

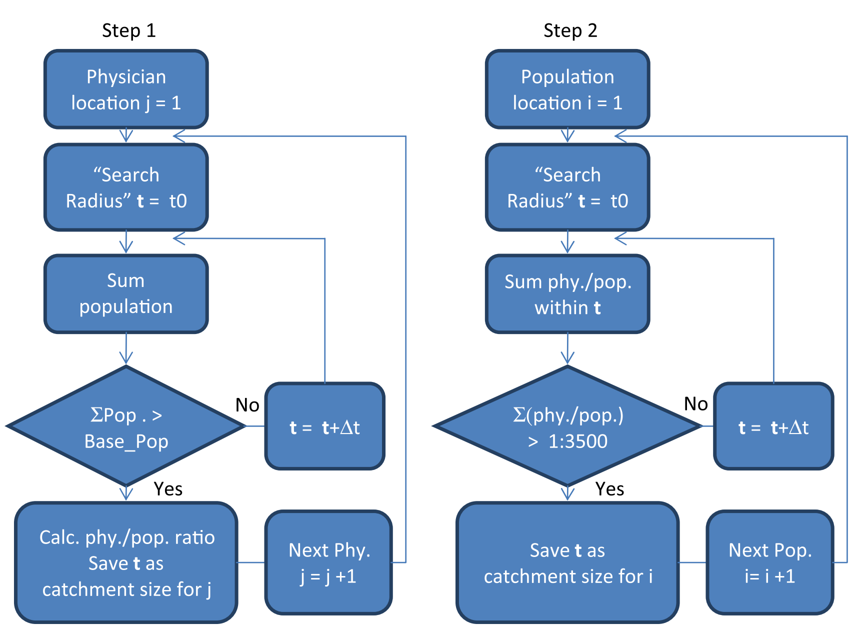

Fig. 1. Flow diagram of steps in determining variable catchment sizes for the 2SFCA method.

2.1. Variable service catchment size

In step 1, for each physician location, search all population locations (population-weighted census tract centroids) within a specified initial travel time t_0 (e.g., $t_0=10$ min) and sum the population. If the summed population is less than the BP threshold, the "search radius" time (or catchment size) is increased by a small increment Δt (e.g., $\Delta t=2$ min) and the process is repeated until the summed population reaches the BP threshold. The travel time at that point is considered the catchment size for that physician location. At this step, the PPR is also calculated and assigned to the physician location.

2.2. Variable population catchment size

In step 2, for each population location, search all physician locations within an initial travel time t_0 (e.g., $t_0=10$ min) and sum PPRs of these physician locations obtained from the first step. If the summed PPR is less than the predefined threshold, the time (or catchment size) is increased by a small increment Δt (e.g., $\Delta t=2$ min) and the process is repeated until the summed PPR exceeds the predefined threshold. The travel time at that point is set as the catchment size for that population location.

2.3. Distance decay function

Once these catchment sizes are determined, the 2SFCA method enhanced with distance decay function (Luo and Qi, 2009) is applied using these newly determined and spatially variable catchment sizes to find the spatial accessibility (i.e., replacing the fixed d_0 as described in Section 1).

Step 1: For each physician location j, search all population locations (k) that are within the catchment of physician location j (C_j), and compute the physician-to-population ratio, R_j, within the catchment area, discounted by distance decay function $f(d_{kj})$:

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le C_j\}} P_k f(d_{kj})} \tag{4}$$

Step 2: For each population location i, search all physician locations (j) that are within the catchment area of population location i (C_i), and sum up the physician-to-population ratios (derived in step 1), R_j, at these locations, discounted by distance decay function $f(d_{ij})$:

$$A_i^F = \sum_{j \in \{d_{ij} \le C_i\}} R_j f(d_{ij}) \tag{5}$$

In other words, there are a total of four steps in the whole process: two steps to determine the catchment sizes and two steps to calculate accessibility. These steps were implemented in a Fortran program. The travel time between origin–destination (OD) pairs only needs to be computed once.

3. Study area and data

To demonstrate the advantages of the V2SFCA method, it has been applied to examine the spatial accessibility to primary care physicians in a group of 10 primarily urban or suburban counties around Chicago in Northern Illinois: Cook, DeKalb, DuPage, Grundy, Kane, Kankakee, Kendall, Lake, McHenry, and Will (see Fig. 2). Since the focus of the paper is to demonstrate methodology, here we report results using 1990 data, which best illustrate the methodology. The population data were extracted from the 1990 Census Summary File 1. In addition to the summary files, the spatial coverages of census tracts and census blocks were generated using the 1990 Census TIGER/Line files. The population density by census tracts is shown in Fig. 2, which

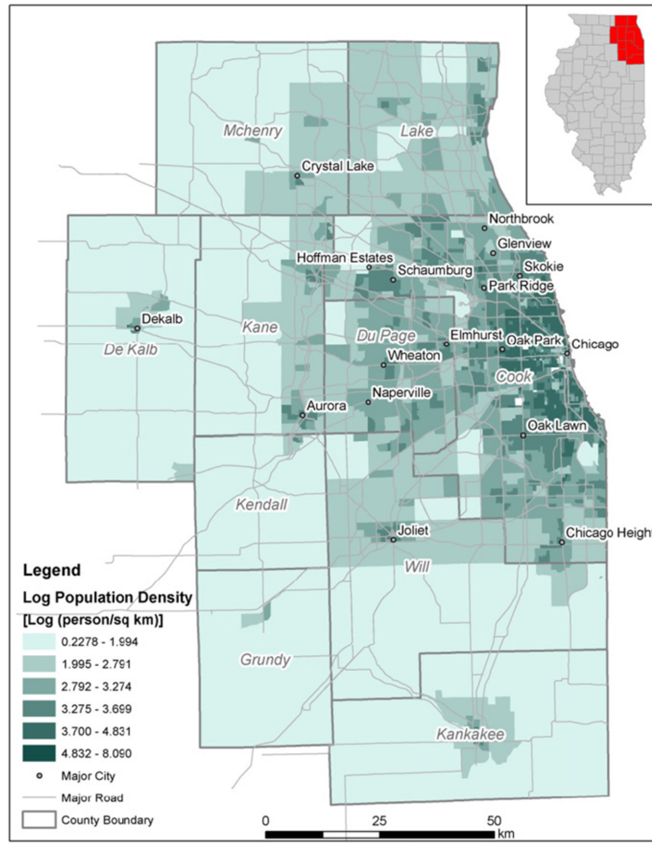

Fig. 2. 1990 population density of study area. Also shown are county boundaries and major cities in the study area. Italicized font labels are county names. Regular font labels are selected cities.

Table 1
Basic statistics of population and physician data of the study area.

	Number of locations	Total
Population	1804	7,507,113
Physician	3990	7645

roughly represents the urban to suburban/rural continuum. Since portions of the study area are suburban/rural in nature with large census tracts, the population-weighted centroid has been used to represent the location of the population in lieu of the geographic centroid (Luo and Wang, 2003). The basic statistics of the population data are summarized in Table 1.

Primary care physician data of Illinois for 1989 were obtained from the Physician Masterfile of the American Medical Association (AMA) and were geocoded based on their office addresses with a matching rate of $>95\%$ using an ArcGIS software. The 1989 data is up to date to December of 1989, and is a good representation of the 1990 data. Physicians practicing at the same location were dissolved into one point with the number of physicians at that location added as an attribute of that point. The basic statistics of the physician data are summarized in Table 1.

4. Calculation and parameters

4.1. Travel time

The travel time between each physician and population location can be calculated using the Origin–Destination (OD) Cost matrix function of ArcGIS Network Analyst Extension. Since this is a computationally intensive process, to reduce computation time, we only computed pairs within 90 min of each other, which resulted in 4,306,699 OD pairs.

4.2. BP and PPR Thresholds

Conceptually, there needs to be some minimum population to support a doctor. This base population often fluctuates between rural and urban areas. In designating Health Professional Shortage Area (HPSA) and Medically Underserved Area or Population (MUA/P), US Department of Health and Human Services (DHHS) uses a 30-minute travel time and a physician-to-population ratio of 1:3500 as thresholds (see (Luo and Qi, 2009) for a brief review and http://bhpr.hrsa.gov/shortage/hpsas/designationcriteria/index.html for details). Following these practices, we used the average population within a 30-minute travel time around the physician locations as our guide to derive the BP threshold in step 1 (which is approximately 500,000 for the study area) and adopted 1:3500 as the PPR threshold in step 2. Of course, other values can be used depending on the specific situations or research contexts. The effects of using different threshold values will be discussed further in Section 6.

4.3. Distance decay functional form

For the purpose of illustrating methodology, we divided each catchment into three equal time zones (e.g., if a catchment is 45 min, then zone 1 is within 15 min, zone 2 from 15 to 30 min and zone 3 from 30 to 45 min) and adopted the simple stepwise Gaussian function to calculate the weights for the three zones (Kwan, 1998; Luo and Qi, 2009):

$$f(d_{ij}) = f(d_{kj}) = f(z) = \exp(-(z-1)^2/\beta) \tag{6}$$

where z is the zone number and

$$z = \begin{cases} 1, & \text{if } 0 < d_{kj} \le \frac{C_j}{3} \text{ or if } 0 < d_{ij} \le \frac{C_i}{3} \\ 2, & \text{if } \frac{C_j}{3} < d_{kj} \le \frac{2C_j}{3} \text{ or if } \frac{C_i}{3} < d_{ij} \le \frac{2C_i}{3} \\ 3, & \text{if } \frac{2C_j}{3} < d_{kj} \le C_j \text{ or if } \frac{2C_i}{3} < d_{ij} \le C_i \end{cases} \tag{7}$$

Here we used $\beta = 1.15$ and obtained the following weights to calculate the spatial accessibility values following the steps described above:

$$W_{kj} \text{ or } W_{ij} = \begin{cases} 1, & \text{if } d_{kj} \text{ or } d_{ij} \in \text{zone } 1 \\ 0.42, & \text{if } d_{kj} \text{ or } d_{ij} \in \text{zone } 2 \\ 0.03, & \text{if } d_{kj} \text{ or } d_{ij} \in \text{zone } 3 \end{cases} \tag{8}$$

Under this implementation, Eqs. (4) and (5) become (note the weights are applied to both steps):

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \le C_j\}} P_k W_{kj}} \tag{9}$$

$$A_i^F = \sum_{j \in \{d_{ij} \le C_i\}} R_j W_{ij} \tag{10}$$

For comparison, we also computed the accessibility using fixed 30-minute catchment sizes and the same distance decay weights for 3 zones. In other words, the only difference here is in the catchment size. Since data outside of the study area was not included in the calculation, caution needs to be exercised in the interpretation of results near the edge of the study area.

5. Results

Table 2 shows the basic statistics of the physician and population catchment sizes using the following parameter values: BP = 500,000 and PPR = 1:3500. This serves as our base case for discussion. The physician catchment size ranges from 14 to 86 min with a mean of 30 min and a standard deviation of 11 min. The population catchment sizes are generally smaller than the physician catchment sizes, ranging from 10 to 68 min with a mean of 21 min and a standard deviation of 11 min. As the physicians are often located in urban centers, they are expected to have larger catchment sizes because they will likely serve surrounding rural populations. On the other hand, population catchment sizes are smaller because urban populations are less likely to seek care in more rural areas (McGrail and Humphreys, 2009b). The spatial distribution of both physician and population catchment sizes are shown in Fig. 3 as circles of different sizes. The catchment sizes for both physician and population locations are smaller in urban areas and larger in suburban/rural areas because there are more doctors available in urban areas, causing people in suburban/rural areas to travel further distances and longer times to obtain care. This catchment size distribution correctly reflects the reality.

Fig. 4 compares the spatial distribution of accessibility scores in the study area using the fixed catchment size of 30-minutes for both physician and population locations and using the variable catchment sizes determined by the new method shown in Fig. 3. Note that distance decay has been considered in both cases using step-wise Gaussian weights of (1.00, 0.42, 0.03; Luo and Qi, 2009) and the only difference is in the catchment sizes. From this case study it is clear that the fixed catchment size method tends to overestimate the accessibility, in both urban and suburban/rural areas, as compared to the variable catchment method. This is the case because urban populations typically do not have to travel 30 min to find adequate numbers of primary care physicians. By using a fixed 30-minute catchment size, the number of physicians available to these populations may have been overestimated. On the other hand, physicians in rural areas often have to serve a larger area and by limiting the catchment size to a fixed 30 min, the population they serve is underestimated, leading to a higher accessibility score. Overall, the V2SFCA method has resulted in more detailed spatial variation of accessibility in urban areas. The high accessibility areas are mostly located around the major towns/cities, e.g., Aurora, Chicago Heights, Elmhurst, Joliet, Naperville, Oak Lawn, and Wheaton (see Figs. 2 and 4). The results using the V2SFCA method thus are more logical and consistent with what we know about physician utilization patterns in urban and rural settings as compared to those of the fixed catchment method. To better compare the two results, accessibility scores by census tract have been plotted in Fig. 5, confirming that the fixed size method overestimates accessibility for nearly all of the tracts as compared to the new method.

Table 2
Basic statistics of the dynamically determined population and physician catchments (measured in travel time in minutes) using different values for base population (BP) and physician-to-population ratio (PPR).

BP	PPR		Min.	Max.	Avg.	Std. Dev.
500,000	1:3500	Physician	14	86	30.02	11.10
		Population	10	68	20.85	11.18
700,000	1:3500	Physician	18	90	34.93	12.37
		Population	10	74	23.29	12.72
380,000	1:3500	Physician	12	74	26.60	10.04
		Population	10	64	19.14	10.10
500,000	1:3000	Physician	14	86	30.02	11.10
		Population	10	70	21.97	11.87
500,000	1:4000	Physician	14	86	30.02	11.10
		Population	10	68	19.91	10.63

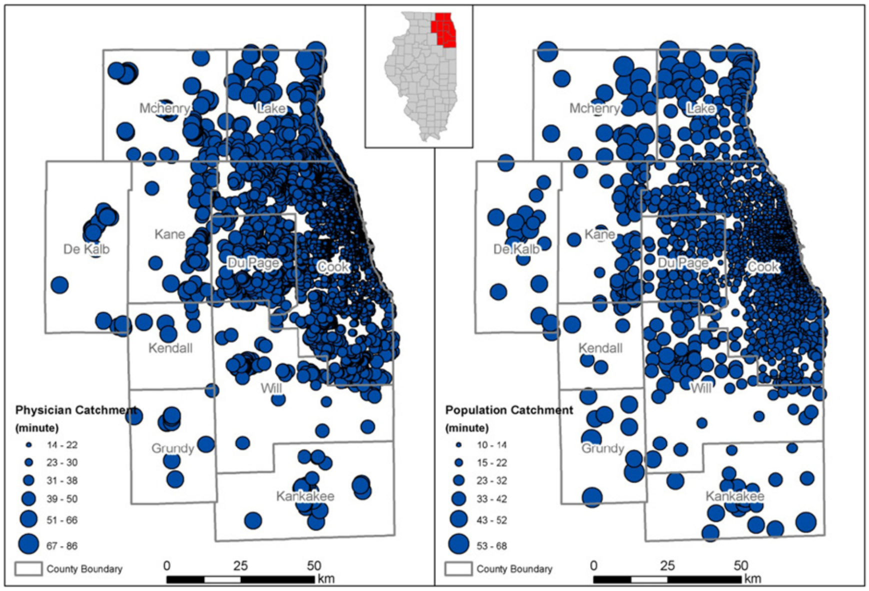

Fig. 3. Catchment sizes for physician locations and population locations. The different size circles are symbols representing different catchment sizes.

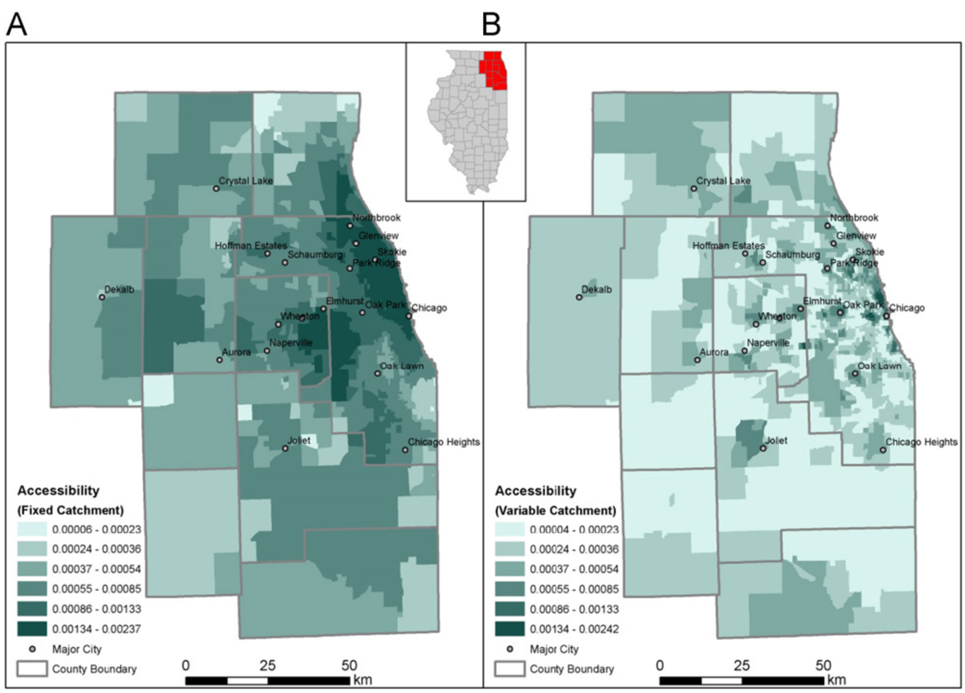

Fig. 4. Spatial distribution of accessibility scores using the fixed catchment size 2SFCA method (A) and the variable catchment size 2SFCA method (B). Note the legends have the same divisions except for the upper and lower limits.

For the more rural areas, we will only examine the counties of Kane and Will, because they are located in the interior of the study area and should be devoid of any edge effect mentioned earlier. From the population density map (Fig. 2), it is evident that the western half of Kane and southern half of Will counties are more rural. However, the fixed catchment size method shows higher accessibility values in those locations, which is counter-intuitive and may reflect more "choices" of physicians in nearby towns rather than actual access to those physicians (McGrail and Humphreys, 2009b). In contrast, the variable catchment size method correctly shows higher accessibilities in the eastern half of Kane and northern half of Will counties, particularly around the population centers of Aurora and Joliet.

6. Discussion

6.1. Parameter sensitivity tests

The V2SFCA method requires the inclusion of two thresholds, BP (for step 1) and PPR (for step 2), both of which can be easily incorporated into the current practices in physician shortage designation. By referencing the 30-minute travel time for defining a rational service area adopted by DHHS, we derived the BP threshold using the mean of populations within 30-minute travel time of all physician locations as our guide. For the application of this method in rural areas, we can derive the BP threshold based on the mean of populations around a larger travel time

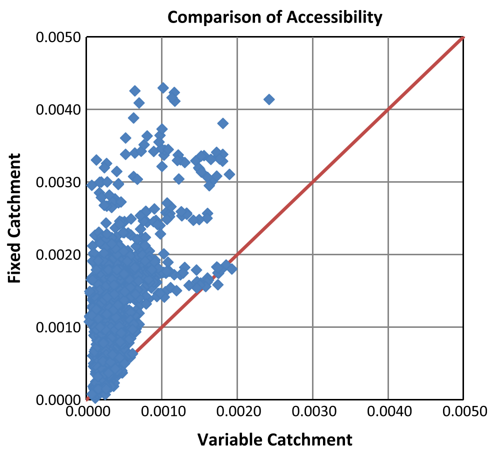

Fig. 5. Comparison of accessibility between fixed catchment and variable catchment methods. The red line is the 1:1 line. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)

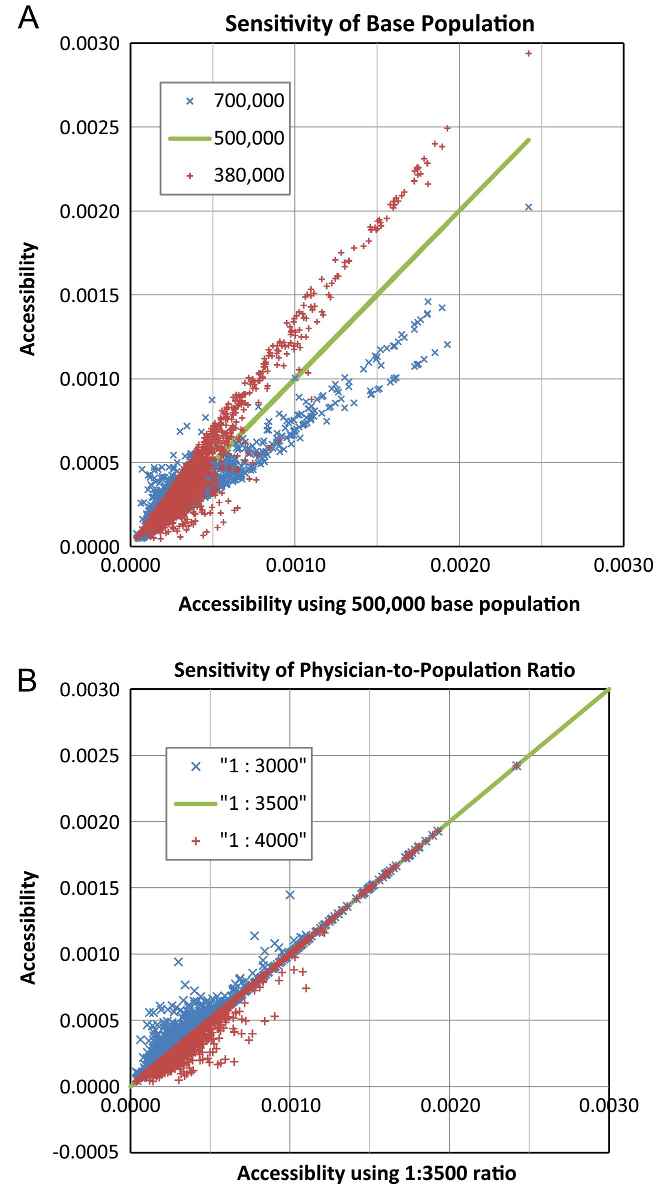

Fig. 6. (A) Effect of different base population (BP) on accessibility result (keeping PPR in step 2 at 1:3500). (B) Effect of different physician-to-population ratio (PPR) on accessibility result (keeping BP in step 1 at 500,000).

(e.g., 60-minutes) of the physician locations. To test the sensitivity of using different BP thresholds on the final accessibility result, we used two different values: 380,000 and 700,000. The spatial patterns of the results are consistent with those shown in Fig. 4B, again revealing much more detailed spatial distribution within urban areas and more intuitively reasonable patterns in rural areas as compared to results using the fixed catchment size method. The large BP threshold tends to result in large catchment sizes (see Table 2) and lower accessibility scores, especially for high accessibility areas (urban centers). This is clearly shown in Fig. 6A, where high accessibility tracts using BP threshold of 700,000 are plotted below the tracts using a BP threshold of 500,000. For these urban centers, the use of a large BP threshold means the catchment will likely expand into rural areas. As such, more rural populations will be included in the catchment, but since there are not many physicians in rural areas, a lower physician to population ratio and lower accessibility score will result (Fig. 6A). The spatial patterns of the differences between accessibilities using different BP thresholds (not shown) confirm the above observation. The reverse is true when using a smaller BP (380,000) (see Table 2 and Fig. 6A).

For the PPR threshold (in step 2), we simply adopted the DHHS's standard 1:3500 ratio used for defining rational service area for physician shortage area designation. To test the sensitivity of using different PPR thresholds on the final accessibility result, we calculated results using two thresholds: 1:4000 and 1:3000 while keeping other parameters the same as in Fig. 4. The spatial patterns of accessibility using higher and lower PPR thresholds are again similar to the results shown in Fig. 4B. Since the BP threshold is kept the same, the physician catchment size is also the same (Table 2). A larger PPR threshold (1:3000) generally resulted in a larger population catchment size (Table 2). Fig. 6B shows that for tracts with lower accessibility (rural areas), a larger PPR (1:3000) resulted in higher accessibility than a smaller PPR (1:3500). For these rural populations, as catchment size is increased to satisfy the large PPR threshold, the catchments tend to expand into urban areas and include more physician locations, thus resulting in higher accessibility. (A similar phenomenon can also be observed for some low accessibility tracts in Fig. 6A for the same reasons.) The reverse is true for the case using a smaller PPR threshold (1:4000). It is interesting to note that for high accessibility points (urban centers) in Fig. 6B, there is virtually no difference in accessibilities from using different PPR thresholds. This is because for these urban centers, expanding the catchment size into rural areas will unlikely gain any more physician locations. The spatial patterns of the differences between accessibilities using different PPRs (not shown) confirm the above observation.

6.2. Distance decay functional form

As discussed in Wang (in press), other distance decay function forms, such as a continuous function (gravity function or Gaussian function), a discrete step-wise function (this paper), or a hybrid function form of the previous two, can be easily incorporated into the new methodology. Luo and Wang (2003) showed that 2SFCA is a special case of gravity model. Recently, Shi et al. (in press) has demonstrated that 2SFCA, gravity model, and kernel density estimator are inherently related. They argued that the different functional forms for determining distance decay weight will not significantly impact the spatial pattern of the estimates, which is a well-accepted conclusion in the kernel density estimation study (Silverman, 1986).

6.3. Policy implications

The fixed catchment size 2SFCA (even with distance decay incorporated) tends to overestimate the accessibility and may result in missing the truly underserved areas. As pointed out before, some of the higher accessibility score in rural areas between towns occurs because the method is measuring more "choices" of physicians in nearby towns rather than actual access to those physicians (McGrail and Humphreys, 2009b). Using the new V2SFCA method would address this problem and allow most efficient and effective use of limited resources to the neediest population in rural areas. In addition, since the BP and PPR thresholds can be easily related to the current practices of physician shortage designation, this method can be readily incorporated into the existing physician shortage area designation methods.

7. Summary

Despite the many advantages of the original 2SFCA method in measuring potential access to primary care, the exclusion of distance decay and the choice of a single constant catchment size greatly limits its potential in certain scenarios, especially in rural areas (McGrail and Humphreys, 2009b). The distance decay issue has been addressed by using a continuous kernel density function (Guagliardo, 2004) or a Gaussian function (Dai, 2010) or using step-wise discrete weights (Luo and Qi, 2009). The major contribution of this paper is to address the issue of fixed catchment size. We introduced an innovative method in determining catchment sizes using the same principle of 2SFCA that considers both demand and supply and dynamically determines the size across the urban, suburban, and rural continuum. Although two thresholds (BP and PPR) are introduced, they can be easily related to existing practices of physician shortage designation. The result of applying this method in the Chicago region has revealed much more detailed variation of spatial accessibility in urban areas. In addition, the spatial accessibility patterns in rural areas are more consistent with intuition, showing the highest accessibility around major cities, which makes more practical sense. Sensitivity tests show that the spatial accessibility from the V2SFCA method in urban areas tends to be more sensitive to BP threshold while that in rural areas tends to be more sensitive to PPR threshold.

We believe the new V2SFCA method we introduced here offers a practical way of determining the proper catchment sizes for both physician and population locations. Since the BP and PPR thresholds can be easily related to the current practices of physician shortage designation, this method can be easily incorporated into existing physician shortage area designation methods.

Acknowledgment

We would like to thank three anonymous reviewers and Assistant Editor Dr. Sara McLafferty for their careful reviews that helped improve the quality of the paper.

References

Aday, L.A., Andersen, R.M., 1974. A framework for the study of access to medical care. Health Services Research 9, 208–220.
Dai, D., 2011. Racial/ethnic and socioeconomic disparities in urban green space accessibility: where to intervene? Landscape and Urban Planning 102, 234–244.
Dai, D.J., 2010. Black residential segregation, disparities in spatial access to health care facilities, and late-stage breast cancer diagnosis in metropolitan Detroit. Health & Place 16, 1038–1052.
Dai, D.J., Wang, F.H., 2011. Geographic disparities in accessibility to food stores in southwest Mississippi. Environment and Planning B-Planning & Design 38, 659–677.
Guagliardo, M.F., 2004. Spatial accessibility of primary care: concept, methods and challenges. International Journal of Health Geographics 3, 3.
Huff, D.L., 2000. Don't misuse the Huff model in GIS. Business Geographies 8 (8), 12.
Joseph, A.E., Bantock, P.R., 1982. Measuring potential physical accessibility to general practitioners in rural areas: a method and case study. Social Science and Medicine 16, 85–90.
Joseph, A.E., Phillips, D.R., 1984. Accessibility and Utilization—Geographical Perspectives on Health Care Delivery. Harper & Row Publishers, New York.
Khan, A.A., 1992. An integrated approach to measuring potential spatial access to health care services. Socio-economic Planning Science 26, 275–287.
Kwan, M.P., 1998. Space–time and integral measures of individual accessibility: a comparative analysis using a point-based framework. Geographical Analysis 30, 191–216.
Luo, W., Qi, Y., 2009. An enhanced two-step floating catchment area (E2SFCA) method for measuring spatial accessibility to primary care physicians. Health & Place 15, 1100–1107.
Luo, W., Wang, F., 2003. Measures of spatial accessibility to healthcare in a GIS environment: synthesis and a case study in Chicago region. Environment and Planning B: Planning and Design 30, 865–884.
McGrail, M.R., Humphreys, J.S., 2009a. The index of rural access: an innovative integrated approach for measuring primary care access. BMC Health Services Research, 9.
McGrail, M.R., Humphreys, J.S., 2009b. Measuring spatial accessibility to primary care in rural areas: improving the effectiveness of the two-step floating catchment area method. Applied Geography 29, 533–541.
Ngui, A.N., Apparicio, P., 2011. Optimizing the two-step floating catchment area method for measuring spatial accessibility to medical clinics in Montreal. BMC Health Services Research 11, 166, http://dx.doi.org/10.1186/1472-6963-1111-1166.
Schuurman, N., Berube, M., Crooks, V.A., 2010. Measuring potential spatial access to primary health care physicians using a modified gravity model. Canadian Geographer-Geographe Canadien 54, 29–45.
Shi, X., Alford-Teaster, J., Onega, T., Wang, D., in press. Spatial access and local demand for major cancer care facilities in the United States. Annals of the Association of American Geographers.
Silverman, B.W., 1986. Density Estimation for Statistics and Data Analysis. Chapman & Hall/CRC, Boca Raton, FL.
Tiwari, C., Rushton, G., 2005. Using spatially adaptive filters to map late stage colorectal cancer incidence in Iowa. In: Fisher, P. (Ed.), Developments in Spatial Data Handling. Springer-Verlag, pp. 665–676.
Wan, N., Zhan, F.B., Zou, B., Chowa, E., 2011. A relative spatial access assessment approach for analyzing potential spatial access to colorectal cancer services in Texas. Applied Geography 32, 291–299.
Wang, F., in press. Measurement, optimization and impact of healthcare accessibility: a methodological review. Annals of the Association of American Geographers.
Wang, L., Roisman, D., 2011. Modeling spatial accessibility of immigrants to culturally diverse family physicians. Professional Geographer 63, 73–91.
Yang, D.-H., Goerge, R., Mullner, R., 2006. Comparing GIS-based methods of measuring spatial accessibility to health services. Journal of Medical Systems 30, 23–32.