



# Using a GIS-based floating catchment method to assess areas with shortage of physicians

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## Abstract

This paper presents a geographic information system (GIS) based floating catchment method for identifying physician shortage areas. The traditional designation methods are primarily regional availability measures, which use administrative boundaries such as counties as the basic spatial units for calculating physician to population ratios and designate shortage based on those ratios. Such approaches have been criticized for their inability to account for either the spatial variations of population demand and physician supply within those boundaries or for population-physician interactions across them. The floating catchment method addresses the internal spatial distribution problem by deriving population data from a smaller unit, the census tract. The potential cross border patient-physician interaction is taken into consideration by using circles of reasonable radius around each census tract centroid as the basic spatial units, which can encompass areas on either side of an administrative border. By varying the radius of the catchment circle, this paper demonstrates that the physician to population ratio is scale dependent and that the greatest variability of the ratios and shortages occur at the most local scales (< 20 miles), which argues for using finer spatial resolution data in shortage designation practice.

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## Introduction

### *Background on Physician Shortage Designation in the US*

The two basic important factors involved in the issue of access to health care services are physicians (supply) and population (demand). Both are spatially distributed and their distributions do not necessary match. Thus access to health care is not uniform across space and access problems are especially pronounced in rural areas and impoverished urban communities (COMGE, 2000; Rosenblatt and Lishner, 1991). The US federal government spends about \$1 billion a year on programs designed to alleviate health care access problems, including providing incentives or awarding financial assistance to providers serving designated shortage areas, such as the National Health Service Corps Program, Medicare Incentive Program, and J-1 visa

waiver program, among others (GAO, 1995). These federal programs depend on two main systems for identifying shortage areas, conducted by the Department of Health and Human Services (DHHS) (GAO, 1995; Lee, 1991). One designates *Health Professional Shortage Areas* (HPSA), the other *Medically Underserved Areas or Populations* (MUA/MUP). Briefly, the criteria for designating HPSA are the following: (1) the geographic area involved is rational for the delivery of health services, i.e., a rational service area; (2) a specified population to full-time-equivalent (PTE) physician ratio representing shortage is exceeded within the area; and (3) resources in contiguous areas are over utilized, excessively distant, or otherwise inaccessible. For primary care HPSA, this designation ratio is 3500:1 (or 3000:1 if there is unusually high needs). In addition, the HPSA can also be designated for a population group (e.g., low income population) or facility (e.g., a correction center). MUA/MUP is designated based on four factors of health service need: (1) population to full-time-equivalent primary care physician ratio; (2) infant

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mortality rate; (3) percentage of the population with incomes below the poverty level; and (4) percentage of the population aged 65 and older. These four variables are applied to a rational service area to obtain a single Index of Medical Underservice (IMU) score between 0 and 100, with 0 representing the most underserved and 100 the best-served area. A rational service area with a score of 62 or less qualifies for designation as MUA/MUP. The rational service area used in both HPSA and MUA/MUP is defined as (a) a whole county (in non-metropolitan areas); (b) groups of contiguous counties, minor civil divisions, or census county divisions in non-metropolitan areas, with population centers within 30 min travel time of each other; and (c) in metropolitan areas, a group of census tracts which represent a neighborhood due to homogeneous socioeconomic and demographic characteristics. The actual designation of both HPSA and MUA/MUP is a tedious process that involves complicated rules for defining the rational service area, estimating PTE, evaluating contiguous resources, etc. The details are discussed in DHHS (1980); Lee (1991); GAO (1995) and the website of Shortage Designation Branch, National Center for Health Workforce Analysis (<http://bphc.hrsa.gov/dsd/default.htm>, accessed July 8, 2002). The rest of the Introduction will review the literature on health care accessibility, followed by a brief discussion of the purpose of this paper.

#### *Types of accessibility*

Health care accessibility can be classified into two broad categories: revealed accessibility and potential accessibility (Joseph and Phillips, 1984; Phillips, 1990; Thouez et al., 1988). Revealed accessibility focuses on actual use of health care services, whereas potential accessibility emphasizes the geographic patterns and aggregate supply of medical care resources. Since both spatial factors (e.g., geographic location, distance) and nonspatial factors (e.g., social class, income, age, sex, etc. (Joseph and Phillips, 1984)) and their interactions (Meade et al., 1988, p.306-311) can influence one's access to health care, each category can be further divided into spatial and nonspatial accessibility (i.e., the  $2 \times 2$  matrix of Khan, 1992). This paper will only focus on potential spatial accessibility, because identifying where the truly underserved populations are located is the essential first step toward any meaningful and effective government intervention programs.

#### *Measures of potential spatial accessibility and scales*

The measures of potential spatial accessibility include regional availability and regional accessibility (Joseph and Phillips, 1984). The regional availability approach is simpler and measures distribution of supply versus

demand within a region, often expressed as a ratio of population to practitioner (or its variation). The region used is usually a predefined area such as a county, a minor civil division, or a census county division. Although the DHHS shortage area designation methods also take into account some non-spatial factors such as age and socio-economic status, they are primarily regional availability measures using predefined administrative boundaries. The advantage of such a regional availability approach is that it is simple and thus straightforward to implement as the data for physician and population are readily available and such boundaries can be easily located in the real world (Florin et al., 1994). In addition, it is also practical to administer federal funding programs because the government infrastructure is already in place (Florin et al., 1994). However, this approach carries the following assumptions that draw sharp criticisms (e.g., Kleinman and Makuc, 1983; Wing and Reynolds, 1988): (1) people within the region have equal access to the physicians within the same region (i.e., the subregion variation of supply and demand and "distance decay" of utilization behavior are ignored), and (2) people within the region do not go beyond that region to seek care (i.e., the boundary of the region is impermeable or self-contained). The first assumption is obviously not true in most cases, especially if a large areal unit such as county is used. Overcoming or ameliorating the problems of the first assumption requires spatially disaggregated data (e.g., census tract or even smaller areal units) as described by Bullen et al. (1996), Curtis and Taket (1989), and Kivell et al. (1990). However, the smaller the areal unit that is adopted, the more likely it is that people will go beyond that areal unit to seek care, thus violating the second assumption. While the second assumption may be true for delivery systems in some countries (such as the provincially based health insurance programs in Canada), it is not true in US, because people often seek care in adjacent or nearby administrative units (Kleinman and Makuc, 1983; GMENAC, 1980; Wing and Reynolds 1988; GAO, 1995; COGME, 1998). Overcoming or lessening the permeability problem related to the second assumption requires spatially aggregated data to higher levels (e.g., groups of counties, Makuc et al., 1991). The two problems can not be easily reconciled. Although step (3) of the HPSA method is intended to consider adjacent areas, the physician to population ratios are still calculated within their respective boundaries and the actual interaction across boundaries is not accounted for. The fact that the whole county or group of contiguous counties can still be defined as rational service areas in the current DHHS systems suggests that the existing methods can easily lead to overestimation in some areas and underestimation in others and thus funding for programs aimed at alleviating access problems based on such designation

may not be channeled to where it is most needed (GAO, 1995).

The problems of using a predefined administrative boundary as the basic unit to determine the adequacy of supply of a service or resource relative to its demand have long been recognized in geography (e.g., *Openshaw and Taylor, 1981*) but are still not well resolved. This is partially due to the complexity of the problem, i.e., both the supplies and demands are spatially distributed and are likely overlapping, and competition exists among the supplies and the demands (e.g., *Huff, 1963, 1964*). The regional accessibility approach considers such potential for complex interaction between supply and demand located in different regions using a gravity model formulation and thus addresses the problems of the regional availability approach. However, the regional accessibility approach is more complex and requires more data input: the location of supply and demand (*Joseph and Phillips, 1984*), traffic network and travel time analysis between supply and demand, and the frictional coefficient in distance decay function (exponent in the gravity model), which has to be determined by physician–patient interaction data and may be region specific (*Huff, 2000*). The physician–patient interaction data can only be obtained through surveys, which are tedious and time consuming, or from physician records directly, which are hard to get due to confidentiality concerns, or from insurance payment sources, which are very expensive. An extensive literature about gravity-based models exists in the areas of retail location, trade area, and location-allocation of resources (e.g., *Huff, 1963, 1964; Berry, 1967; Berry and Parr, 1988; Rushton et al., 1977; Rushton, 1979; Beaumont, 1981; Eiselt, 1992; Church, 1999*). These models, which deal with supply and demand of resources or services, could be applied to refine the process of determining health service supply and demand and thus define physician shortage areas (e.g., *Knox, 1978; Joseph and Bantock, 1982; Thouez et al., 1988; Khan, 1992; Rushton et al., 1977; Huff, 1963, 1964; Shen, 1998*). Despite the superiority of the regional accessibility measure and the advancement and refinement made in past three decades, current DHHS shortage designation methods are still primarily based on regional availability measures. This is perhaps because of the ready availability of data and practicality of administering funding for the regional availability measures on the one hand and the difficulty in obtaining patient visit data to determine friction coefficients (confidentiality concerns among other things) and the difficulty in administering the final results for accessibility measure (continuous across space) on the other hand. Even the most recent proposed revision of the shortage area designation is still primarily a regional availability measure, although the smaller census tract areal units are favored in the proposed guideline (*DHHS, 1998*).

### *Purpose of the paper*

If the government intervention programs are to achieve their goals of alleviating health care access problems, the shortage designation method needs to more accurately reflect demographic and behavioral realities (*COGME, 1998*), i.e., both physicians and population are spatially distributed and the availability of services depends, not only upon the supply of resources in a community, but also the supply of such resources in neighboring communities and the distance and ease of travel among them (*Kleinman and Makuc, 1983, p. 543*). Given the appealing simplicity and practicality of regional availability measures and the fact the DHHS still uses such measures, this paper presents a GIS based method that can reveal more spatial variations by taking advantage of fine resolution spatial data and at the same time addresses the permeability problem associated with regional availability method. The purposes of this paper are (1) to demonstrate the principle of the floating catchment methodology with a simple case study in northern Illinois, and (2) to show that the greatest variability in physician to population ratios occurs at the most local scales, suggesting that finer spatial resolution data should be used in shortage area designation. The following section describes the floating catchment method and its implementation in GIS. This method will then be applied to counties surrounding DeKalb in northern Illinois region after a brief discussion of the study area. The results will be discussed and conclusions drawn, followed by a brief discussion of ongoing research and future directions.

### **Floating Catchment Method (FCM)**

The floating catchment method (FCM) has been used in job accessibility studies (*Peng, 1997; Wang, 2000*). However, to the best of the author's knowledge, it has not been applied to physician-shortage area designation. Spatially distributed population count (at census tract or block group level) and the number of physicians (by zip code or from GIS address matching) in the study area are the only inputs required for the analysis. Instead of using a predefined administrative boundary to compute the physician to population ratio, FCM defines the basic unit within which to calculate this ratio as a circle of some reasonable radius centered on the census tract centroid. This is somewhat similar to hospital market areas defined by geographic distance (e.g., *Morrill and Earickson, 1968*), but the circles in FCM are centered on population centers and they move across space. The reasonable distance that a person is willing to travel to see a doctor (radius of the circle) may be different for different people or for different types of care, because people of different age, ethnicity, social status, or living in different areas (urban vs. rural) perceive distance differently and people may be willing to

travel a longer distance to seek specialized care (Parkin, 1979; Meade et al., 1988, p. 307–308; Guidry et al., 1997). What is reasonable should really be determined by actual utilization data and should vary according to the study purpose. However, several attempts to obtain such data by the author failed because of confidentiality or cost. As the focus of the paper is to demonstrate the methodology, a number of different radii will be explored and the effects of using different radii will be discussed (see the results section). Conceptually, it is preferable to use travel time instead of distance, as travel time is more directly related to service accessibility (e.g., McGuirk and Porell, 1984; Wang, 2000). However, there is a high correlation between travel time and straight-line distance (Phibbs and Luft, 1995). Thus, for simplicity and for demonstrating the methodology, a straight-line distance is adopted in this paper. This method can be easily implemented in GIS by using its buffer and overlay functions. Specifically, the following steps are involved:

- (a) Draw a circle<sup>1</sup> centered on the centroid of a census tract. The radius of the circle is the reasonable distance that a person is willing to travel to see a doctor. The circle is the catchment of that census tract.
- (b) Overlay the circle with population and physician data to determine the population and the number of physicians falling within the circle. For simplicity, centroids of census tracts or zip codes are used to represent their respective polygons, i.e., using points to represent areas. In other words, this representation assumes that the entire population of a census tract is concentrated on its centroid and all physicians working in the same zip code area are located at its centroid.<sup>2</sup> With this assumption, the overlay operation is simplified to point-in-polygon overlay, which can be conducted quickly and reliably in GIS.
- (c) Compute the physician to population ratio<sup>3</sup> within that circle using numbers of physicians and people obtained in step (b) and assign the ratio value to the

census tract under consideration:

$$R_i = \frac{Phy_i}{Pop_i}, \quad (1)$$

where  $R_i$  is the physician  $Phy_i$  to population  $Pop_i$  ratio for census tract  $i$ ;

- (d) Repeat steps (a)–(c) for rest of the census tracts, i.e., moving the catchment over space;
- (e) Run a GIS query to identify all the tracts with a ratio less than the DHHS standard (1:3500 for primary care) as the shortage areas.

As an example, let us consider two adjacent counties schematically shown in Fig. 1. For illustration purposes, let us also assume that each census tract has only one person residing within its boundary and is located at its centroid and each physician location has only one physician practicing there. Under this assumption, the circle centered on the centroid of census tract #2 encloses 7 persons (7 black dots) and 1 physician (1 cross) and thus the physician to population ratio of this circle is 1/7. This ratio is assigned to census tract #2. Similarly, the ratio for tract #3 is 2/5. The ratio for the rest of the census tracts can be determined similarly by moving the circle from tract to tract (hence the name floating catchment). In the actual calculation, the number of physicians is the sum of the physicians of each zip code area whose centroid falls within the circle and the population is the sum of each tract's population whose centroid falls inside the circle.

There are two advantages of the floating catchment method. (1) It reveals more detailed spatial variations within a county because a census tract is much smaller than a county. (2) It accounts for the potential patient-physician interaction across county boundaries because the floating catchment can encompass population and physicians in adjacent counties (e.g., both circles shown in Fig. 1 cross the county border). However, it should be pointed out that this method still assumes equal access within the basic unit, even though its negative impact is greatly reduced since the basic units used here (floating catchment circles) are much smaller than those used in traditional methods (mostly counties).

## Application to Illinois

### Study area and data source

To illustrate the principle of the floating catchment method, this paper applies it to examine the primary care physician shortage conditions in a group of 9 counties surrounding DeKalb in northern Illinois (Fig. 2). The study area is mostly suburban or rural, located west of Chicago. The 1990 population ranges from 30,806 in the smallest county to 317,471 in the

<sup>1</sup>Circle, catchment, and buffer are used interchangeably in this paper. Buffer is a GIS term referring to a region that is less than or equal to a specified distance from one or more features (Bolstad, 2002, p. 246). A buffer around a point feature is a circle.

<sup>2</sup>Other variations such as using more detailed census block group data, counting partial population of a census tract according the percentage of its area falling within the catchment, or using more detailed address matched physician location can be also be implement, but the basic methodology is the same.

<sup>3</sup>The physician to population ratio (as opposed population to physician ratio) is used to avoid numerical overflow due to zero denominator for some census tracts that may not contain any physician.

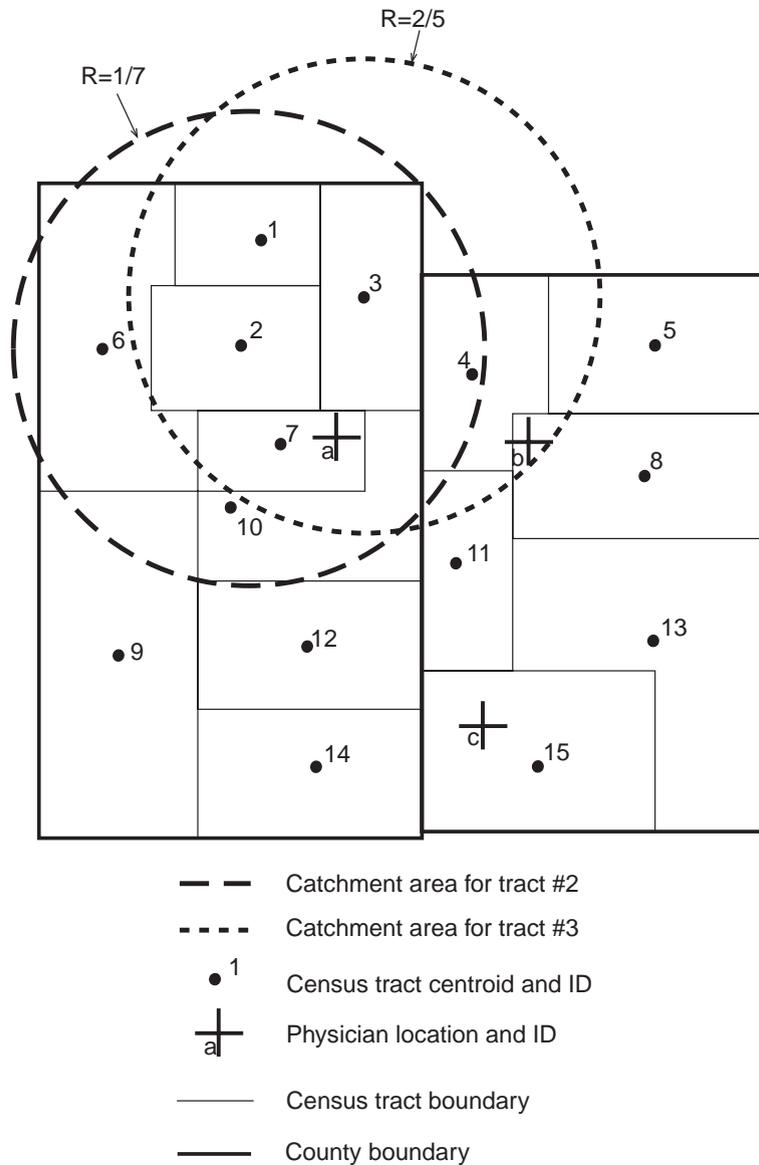


Fig. 1. Floating catchment method for identifying physician shortage areas. Instead of using the large administrative boundary such as county as the basic unit, a small circle (catchment) drawn around each tract centroid is used as the basic unit to calculate the physician population ratio. The radius of the circle is the reasonable distance a person is willing to travel to see a physician. This circle moves from tract to tract, thus shortage variation from place to place can be identified. R's are the physician to population ratios under the assumption that each census tract has only one person within it and each physician location has only one physician there.

largest and the study area total is 1,089,038. There are a total of 242 census tracts in the study area, with a mean population per tract of about 4500 and standard deviation of 2023. Primary care physicians<sup>4</sup> were

<sup>4</sup>Primary care physicians are family physicians, general practitioners, general internists, general pediatricians, as well as some obstetrician-gynecologists (Cooper, 1994).

selected for this study because these physicians are an integral component of a rational and efficient health delivery system and they represent the first line of contact for the population. Only after seeing one of these physicians are many of the ill sent to see specialists. With soaring healthcare costs, the need for primary care physicians also increases, because prevention is at the heart of primary care and good primary care can avoid

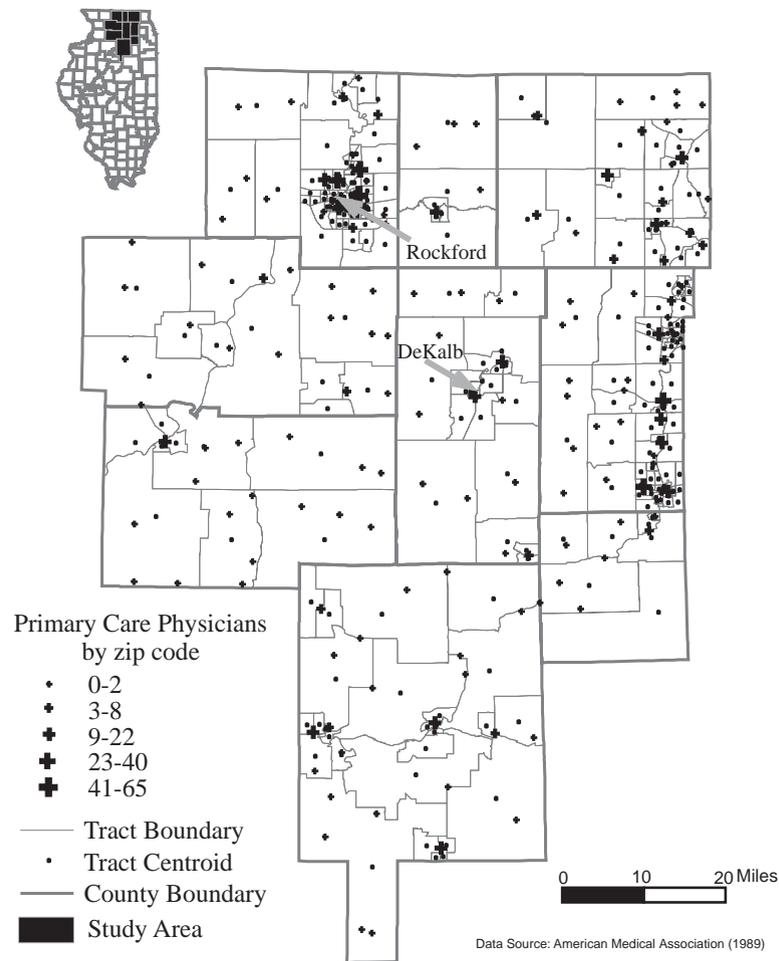


Fig. 2. Distribution of primary care physician for 1989 in study area georeferenced by zip code. Also shown are the census tract boundaries and their centroids. Arrows point to the place names discussed in the text.

or reduce costly, unnecessary diagnostic and treatment intervention by specialists (Lee, 1995). However, the methodology presented here can be easily adapted to identify shortage areas of other health care specialties, and at state and national levels.

The primary care physician data of Illinois for the year 1989<sup>5</sup> were purchased from the Physician Master File of the American Medical Association via Medical Marketing Service Inc. The population data at the census tract level for the year 1990 were obtained from US Census Bureau. The census tract level data was selected because this is the lowest level of aggregation that also has the social economic information needed in the existing DHHS designation methods. Ideally, the physician locations should be obtained by matching

their addresses to the Topologically Integrated Geographic Encoding and Reference (TIGER) street files with GIS software. This geocoding process converts the address information of a physician to x and y coordinates of a point on the map by matching address name and interpolating the address range to those stored in a digital map (TIGER street file) in GIS. However, a significant number of records in the Physician Masterfile only have “P. O. Box” addresses, which are not geocodable. The most up-to-date street files are usually offered only by commercial companies and are very costly. To illustrate the principle of the floating catchment method, the location of a physician is simply taken as the centroid of zip code of that physician’s address in the physician masterfile. Physicians within the same zip code are assumed to work at the zip code centroid location. Zip codes are chosen because they represent a finer resolution than counties and the zip code based data are readily available and have also been

<sup>5</sup> The 1989 data set is the only available historic data that is the closest to 1990 and is current up to December 31, 1989. Thus it is assumed to represent the physicians in 1990.

used extensively in health research (e.g., Ng et al., 1993; Parker and Campbell, 1998; Knapp and Hardwick, 2000). However, this does not mean that the zip code data are free of problems. Zip codes are developed for the purpose of delivering mails and may be totally unrelated to health care or demographic data. For example, some “point zips” are for small rural post offices that have only a set of boxes for mail pickup. Many in urban areas are for office building or government subdivisions that are unrelated to either physician or potential patients (Wing and Reynolds, 1988). In addition, studies on errors associated with using centroid point to represent area indicate that the subject spatial patterns may be at least slightly different if more accurate data are used (Gatrell et al., 1991; Boyle and Dunn, 1991; Gatrell, 1989). Although application of FCM in this paper will be based on zip code data and using centroid to represent area, the principle of the methodology can be easily adapted to any other geographic unit considered appropriate by the user as long as the unit is small enough to provide adequate resolution and the physician and population data is available at that unit level. More accurate spatial data may change the pattern of the result but the principle of the methodology, which is the focus of this paper, is the same. The spatial distribution of primary care physician georeferenced by zip code for the year 1989 is shown in Fig. 2.

## Results and discussion

The focus of this paper is to introduce a methodology that improves over some of the limitations imposed by the use of artificial administrative boundaries. Thus, not every aspect of the DHHS shortage designation methods is considered in this paper (e.g., the possibility of using a ratio of 1:3000 for areas showing special needs or using FTE concept for physician count) and the results shown here are not directly comparable with those generated by DHHS methods, which are usually in the form of a text list published in Federal Register (DHHS, 1990).

In order to evaluate the effects of spatial scale on physician to population ratio, and because the reasonable distance a person is willing to travel to see a doctor may vary according to his/her age, race, social economical status, etc. and according to different types of care sought (Parkin, 1979; Meade et al., 1988, p. 307–308; Guidry et al., 1997), a series of radii ranging from 5 to 125 miles (with a 5-mile increment for radii below 50 miles and 25-mile increment for the rest) was used when applying the floating catchment method to the study area. The shortage areas using a 1:3500 threshold physician to population ratio for radii ranging from 5 miles to 35 miles are shown in Fig. 3,<sup>6</sup> along with the

published 1990 HPSAs within the study area (DHHS, 1990). The following observations can be made from Fig. 3. First, this method reveals more detailed spatial variation within a county because finer scale census tract level population data were used and the potential cross border interaction between physician and population were taken into account by “floating” the catchment circle from tract to tract, removing the limitation imposed by the predefined administrative boundary used in traditional methods. Second, shortages are mostly located in more rural areas (which is usually characterized by their large sizes of census tracts). This is consistent with the findings of other studies (e.g., COMGE, 2000; Rosenblatt and Lishner, 1991). However, this method can reveal not only the spatial variation but also the severity of shortages and level of surpluses in choropleth maps of the physician to population ratio (not shown). Third, the smaller the radius used, the more the number of shortage areas identified (compare Fig. 3a–c). This effect is seen more clearly in Fig. 4, where the physician to population ratio is plotted against the radius of the catchment, along with the standard 1:3500 ratio line. As the radius increases, the ratio of a particular census tract goes up and down, but eventually converges to one value, which is equal to the total number of physicians divided by the total population of the study area. This is because as the radius becomes large enough, no matter where you draw the circle in the study area, the whole study area will be enclosed in the circle. Fig. 4 shows that the greatest variability of the physician to population ratio occurs at the most local scales and the radius of the catchment that can identify most shortage areas (i.e., ratio < 1:3500) is less than 20 miles. This value coincides with the reasonable distance for primary care often taken in the literature, i.e., 30-mins of travel or 20 miles for primary road conditions (e.g., Lee, 1991). The 30 mins travel time is also the limit used in DHHS methods to define rational service area and to determine whether continuous resource is excessively distant. This result suggests that the populations that are most adversely affected by poor access are those who cannot easily travel the 20 miles or less distance and these populations are usually located in rural areas (Fig. 3a and b). Fourth, as mentioned before the FCM implemented here is only for demonstrating the principle of the methodology and its results are not directly comparable with those existing HPSAs, nonetheless such comparison does provide some insight. The only existing HPSAs designated in 1990 in the study area (blackened areas in Fig. 3) are located in the inner city of Rockford, which were probably designated due to nonspatial factors such socio-economic status. All the other areas not designated, but could be potentially designated with FCM incorporated using a radius of less than 20 miles, are probably due to the fact that

<sup>6</sup>The rest of radii (> 35 miles) resulted in no shortage areas (also see Fig. 4) and thus are not shown.

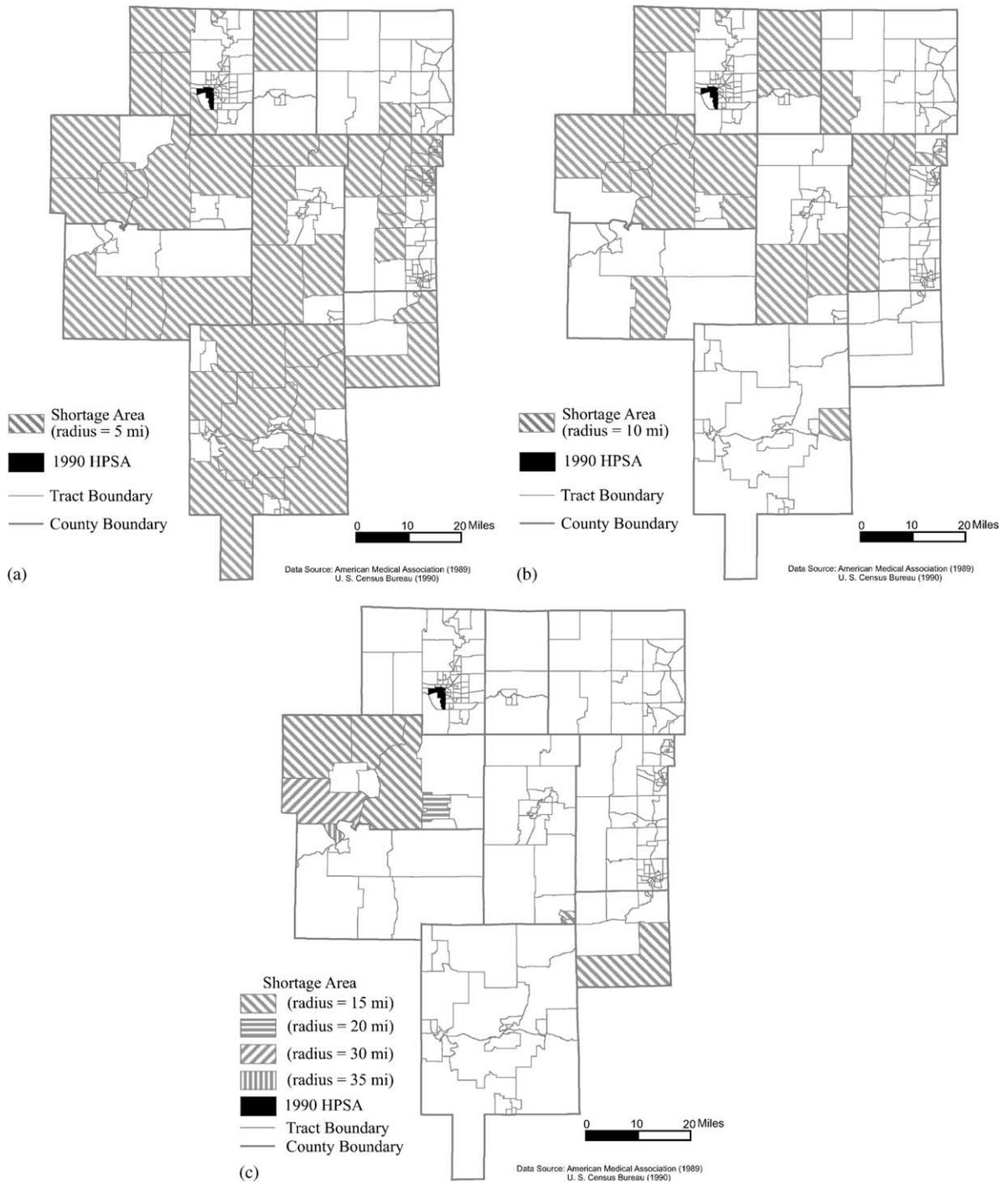


Fig. 3. Primary care physician shortage areas identified using floating catchment method with a threshold physician to population ratio of 1:3500 used in existing DHHS methods, (a) radius of catchment = 5 miles; (b) radius of catchment = 10 miles; (c) radius of catchment = 20, 30, 35 miles. Radii greater than 35 miles resulted in no shortages and thus are not shown. Also shown are the published 1990 HPSAs (DHHS, 1990).

existing HPSA designation used larger areal units (such as counties) and thus masked out local spatial variability. Thus the existing method may fail to reveal the

most adversely affected population and the limited federal funds may not be delivered to those most in need.

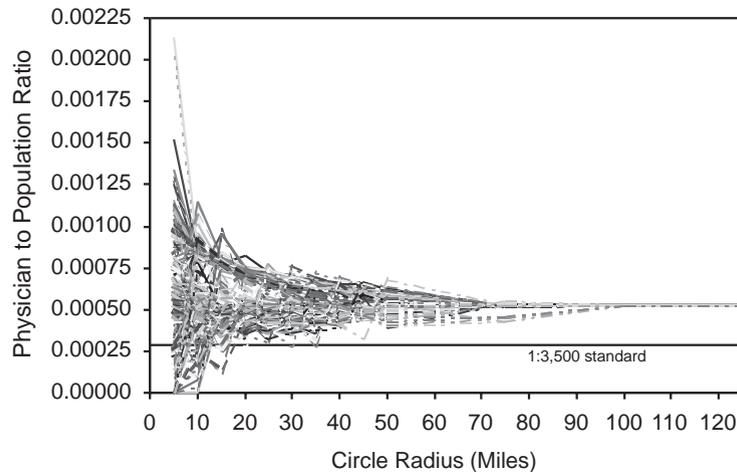


Fig. 4. Population to physician ratio as a function of spatial scale (radius of the catchment). Most variability in ratio and shortage (ratio < 1:3500) occurs at the most local scale (< 20 miles).

Although Fig. 3c does show a few census tracts being identified as shortage with the radius equal or greater than 20 miles (this is also reflected on Fig. 4), these are probably due to the edge effect of the study area. As the radius increases, more populations are included, but the increase in physician number is limited because these tracts are located close to the edge of the study area and physicians outside of the study area are not considered. Thus the actual health care status for the areas close to the edge of the study area may not be accurately reflected. This is limited by the size of the study area, which can be easily addressed by expanding the study area to include surrounding counties.

As pointed out previously, this method still assumes that people within a catchment have equal access to physicians within that same catchment. In other words, a patient living 1-mile from the doctor is assumed to have same accessibility as one living 10 miles from the doctor, as long as both patients fall within the circle. To truly account for this shortcoming, the gravity-based spatial accessibility model has to be used (e.g., Knox, 1978; Joseph and Bantock, 1982; Thouez et al., 1988; Khan, 1992; Rushton et al., 1977; Huff, 1963, 1964; Shen, 1998). This would involve more complicated calculation, traffic network and travel time analysis, and require additional origin based data to estimate parameters such as friction coefficient (Huff, 2000), which is beyond the scope of this paper.

## Conclusions

By taking advantage of the GIS buffer and overlay capabilities and by incorporating population and physician data at a finer geographic resolution, the method presented here replaces large administrative

boundaries (such as counties) with smaller circles centered on census tract centroids as the basic units for calculating physician to population ratio when determining areas of physician shortage. The method has two advantages. First, it can reveal more detailed spatial variation within large administrative areas such as counties. Second, it considers potential interaction between patients and physicians across administrative borders. In addition, by varying the radii of the floating catchments, it is demonstrated that the physician to population ratio is scale dependent and that the greatest variability in this ratio occurs at the most local scale. The radius of the catchment that can identify most shortage areas is less than 20 miles (using the 1:3500 physician to population ratio criterion of DHHS). This result indicates that the populations that are most adversely affected by poor access are those (usually rural residents) who cannot easily travel the 20 miles or less distance. Thus it is preferable to use smaller spatial units to compute the physician to population ratio upon which shortage areas are designated.

## On-going and future work

The principle of the FCM methodology is reported here in a simplified way. The following improvements can be made in our on-going and future research. (1) Population locations (taken as census tract centroids in this paper) can be more accurately represented by population weighted centroids. This will be especially helpful for those large rural tracts. (2) Physician locations (taken as physicians' zip code centroids in this paper) can be more accurately represented by matching physician addresses to updated digital street database and thus address the problems associated with using zip

codes. (3) Shortcomings of using straight line distance (radius) to define the floating catchment can be overcome by using GIS simulated travel time on street network. This has been done and the results will be forthcoming in a book chapter (Luo and Wang, 2003). (4) The problem associated with equal access assumption can be addressed by incorporating elements of the gravity model into the FCM to account for the distance decay within the catchment.

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