

Research paper

An adapted two-step floating catchment area method accounting for urban–rural differences in spatial access to pharmacies

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Abstract

Objective To adapt the two-step floating catchment area approach to account for urban–rural differences in pharmacy access in the United States.

Methods The urban–rural two-step floating catchment area method was described mathematically. To calculate urban–rural two-step floating catchment area measure, census tracts and pharmacies within the study area (Southeastern Wisconsin) were classified as urban, suburban or rural, and then different catchment area sizes (2, 5 and 15 miles) were applied, based on the Centers for Medicare & Medicaid Services (CMS)' criteria for Medicare Part D service access within urban, suburban and rural areas. The urban–rural two-step floating catchment area measures were compared to traditional two-step floating catchment area measures computed using three fixed catchment area sizes (2, 5, and 15 miles) by visually examining their spatial distributions. Associations between the four pharmacy accessibility measures and selected socio-demographics are calculated using Spearman's rank-order correlation and further compared.

Key findings The urban–rural two-step floating catchment area measure outperforms all the fixed catchment size measures and has the strongest Spearman correlations with the selected census variables. It also reduces the number of census tracts characterized as 'no access' when compared to the original measures. The spatial distribution of urban–rural two-step floating catchment area pharmacy access exhibits a more granular variation across the study area.

Conclusions The results support our hypothesis that spatial access to pharmacies should account for urbanicity/rurality patterns within a region.

Keywords: two-step floating catchment area; spatial accessibility; urban–rural differences, pharmacy access

Introduction

Lack of spatial access to health care, be it to providers, services or pharmacies, has been identified as a key contributing factor to urban–rural health disparities.^[1,2] Pharmacies play a special role not only in dispensing medications, but also offer a variety of services to communities and their residents.^[3] Pharmacies are more available and accessible to residents than other types of healthcare because they operate for longer hours and more days per week, and they welcome walk-in or phone consultations instead of requiring appointments.^[4]

However, there is a sparse literature focusing explicitly on the spatial accessibility of pharmacies. Among existing studies, simple indices such as distance/time to the closest pharmacy,^[5–11] and the number of pharmacies^[12] or pharmacy density^[13,14] within a defined area are the most often used measures, corresponding to proximity- and container-based methods. Two studies embraced the food-desert approach developed by the United States Department of Agriculture (USDA) to identify pharmacy deserts,^[4,15] which incorporates proximity and pharmacy coverage as well as socioeconomic characteristics. Another relatively advanced method, kernel density estimation (KDE) has been employed to study pharmacy access.^[16,17] Compared to proximity- and container-based methods, the KDE method emphasizes supply capacity, proximity and spatial variation due to distance decay effects. However, demand-side factors such as competition intensity for pharmacies and population distribution patterns are not accounted for in neither the KDE nor USDA method. The gravity model and the two-step floating catchment area (2SFCA) model are more recent and complex approaches and have the advantage of considering both supply and demand as well as their interactions. No studies have applied a gravity model to measure pharmacy access, and to our knowledge, only one study has applied the 2SFCA method, and only in one metropolitan area (Baton Rouge, LA, USA).^[18] Compared to the gravity model, the 2SFCA method introduced by Luo and Wang^[19] has been more widely applied to questions of health care access,^[20] and is easy to implement and intuitive to interpret.^[21] Given all the advantages of 2SFCA, we adopted this method to evaluate the spatial accessibility of pharmacies across the USA.

Built upon the concept of ‘catchment area’ capturing proximity, the 2SFCA model intertwines all the other components necessary for conceptualizing accessibility (including supply, demand, interaction and competition) into a two-step procedure. First, within a prespecified catchment area of each facility (supply), the number of the demands is summed then the supply-to-demand ratio for the facility is computed. In this way, competition for using a specific facility could be quantified. More demand or less supply will result in a smaller ratio, implying higher competition. The second step focuses on the catchment area of each demand, within which all the facilities are identified, and their supply-to-demand ratios are summed up. This ratio summation is ultimately the accessibility measure for each demand. Because 2SFCA measure is usually of small value, it is common to multiply the values by a large value, such as 10,000. Then, the inflated 2SFCA score can be roughly interpreted as equivalent to a density measure (for example, pharmacies per 10,000 residents in the study of pharmacy access).

A major critique of the 2SFCA method is the use of a same-sized catchment for every demand or supply location, regardless of that location’s characteristics. This was referred as the ‘one size for all’ problem by McGrail and Humphreys.^[22] This problem is evident when the study area covers places with systematically different

characteristics, such as the coexistence of urban and rural areas in a single study area. To address this issue, McGrail and Humphreys proposed dynamic catchment sizes based on population sizes or densities to reflect ‘expected’ service and population catchments and implemented five catchment size levels corresponding with five remoteness levels outlined by the Australian Bureau of Statistics when evaluating primary health care access for rural Australia.^[2,22,23] There is, however, no accessibility research in North America that uses different catchment sizes according to the characteristics of different parts of a region, for example, the level of urbanicity, rurality or remoteness as the Australian researchers proposed. The US scholars, Luo and Whippo, addressed the issue differently. Their approach is to generate a catchment area that ensures pre-defined levels of base population and physician-to-population ratio are met, resulting in various catchment sizes for localities.^[24] The method is independent of any standards that characterize and categorize places. However, the use of the same base population and physician-to-population ratio for all places could be a limitation, because real differences do exist between urban and rural areas.

The ‘one size for all’ problem is especially relevant to assessing pharmacy access in the USA. First, like seeking health care,^[24] rural residents generally travel a longer distance to get medications from pharmacies (usually by driving), compared to urban populations. One study examining geographic accessibility to retail pharmacies among elderly persons in Illinois showed that the travel distance to the nearest pharmacy was six times greater in rural areas (5.9 miles) than in urban areas (0.9 miles).^[6] Second, urban–rural differences in pharmacy access have been implicitly acknowledged in regulation 42 C.F.R. § 423.120(a)(1) by the CMS. The standards for convenient access to a network retail pharmacy codified in CMS regulations require that at least 90% of Medicare beneficiaries in *urban* areas, 90% of Medicare beneficiaries in *suburban* areas, or 70% of Medicare beneficiaries in *rural* areas have access to network pharmacies within 2, 5 or 15 miles of their residence, respectively.^[25] Urban, suburban and rural areas in the regulations refer to five-digit ZIP codes with different population density levels, greater than 3,000, less than 1,000 and 1,000–3,000 people per square mile for urban, rural and suburban zip codes, respectively.

However, the only one study on assessing spatial accessibility of pharmacies using 2SFCA in the USA used fixed catchment area sizes,^[18] and the city setting of its study area may not demand a recognition of the intuitive difference in travel expectations to a pharmacy for urban versus rural residents. This study aims to fill this methodological gap by proposing an adaptation of the original 2SFCA method to account for urban–rural differences in pharmacy access in the context of US geographies. It also contributes to the empirical studies of pharmacy accessibility and health outcomes using the 2SFCA approach by adding a case study of southeastern Wisconsin.

Methods

The urban–rural two-step floating catchment area method

The proposed urban–rural two-step floating catchment area (UR-2SFCA) (a new name mainly for reference purpose) method includes additional steps to be undertaken before the original two-step procedure of 2SFCA to differentiate supply and demand locations into urban, suburban or rural (U/S/R) types. First, each census tract is classified as U/S/R based on the proportion of census blocks it contains that are classified as urban versus rural (described below).

Second, each demand location (here, the population-weighted mean center of each census tract) and each supply location (pharmacy address) is classified as U/S/R based on the designation of its census tract. Third, following the CMS schema, the catchment size of each pharmacy or each tract is determined based on its U/S/R type. For urban pharmacies or tracts, the catchment size is a 2-mile network-based distance. For suburban or rural ones, the corresponding catchment sizes are 5- and 15-miles.

Fourth, for each pharmacy location j , search all population locations (k) that are within the catchment area of pharmacy j (D_{URj}), and compute the pharmacy-to-population ratio, R_j , within the catchment area

$$R_j = \frac{S_j}{\sum_{k \in \{d_{kj} \leq D_{URj}\}} P_k} \quad (1)$$

Fifth, for each population location i , search all pharmacy locations (j) that are within the catchment area of population location i (D_{URi}), and sum up the pharmacy-to-population ratios (derived above), R_j , at these locations

$$A_i^F = \sum_{j \in \{d_{ji} \leq D_{URi}\}} R_j = \sum_{j \in \{d_{ji} \leq D_{URi}\}} \frac{S_j}{\sum_{k \in \{d_{kj} \leq D_{URj}\}} P_k} \quad (2)$$

Where i (or k) is demand, j is supply, d_{ij} (or d_{kj}) is the distance between i and j (or k), D_{URi} or D_{URj} represents the threshold travel distance/time from location i or j depending on the type (urban/suburban/rural) of the location, P_k is the total demand (or the total population) at demand location k that falls within the catchment area of supply location j (that is, $d_{kj} \leq D_{URj}$) with a capacity S_j , a supply to demand ratio R_j at supply location j that falls within the catchment area of demand location i (that is, $d_{ji} \leq D_{URi}$), n and m are the total numbers of supply locations and demand locations, respectively. A larger value of A_i means a better accessibility at a demand location.

The capacity of all the pharmacies (S_j) was assumed to be one, due to the insufficient quality of the data for the number of pharmacists. The travel distance between supply (pharmacy) and demand (tract population center) locations is measured along the street network, calculated using the Origin–Destination (OD) Cost matrix function of ArcGIS Network Analyst Extension.^[26] All the steps are implemented in R.^[27]

The method we proposed is adapted from the original 2SFCA method, not from the popular enhanced-2SFCA approach which improved 2SFCA by including a distance-decay function in the standard two steps,^[22,28] mainly because the CMSs regulations we followed employed fixed-distance and their evaluation report did not consider distance-decay.^[25]

Comparison of original and adapted two-step floating catchment area measures

The results of the UR-2SFCA approach were compared to traditional 2SFCA measures of pharmacy accessibility using a fixed catchment area size. Three single distances (2, 5 and 15 miles) were employed, resulting in three distinct estimates of pharmacy accessibility for all tracts across the region.

To evaluate the effectiveness of each approach, visual comparisons of the spatial patterns of the four pharmacy access measures were made and evaluated, based on local knowledge of the study

area. Then different accessibility measures were correlated with selected socio-demographic indicators.

Two socio-demographic variables, percent of households below the poverty level and percent African American population, are included in the correlation analyses. These variables were selected because they are among the factors affecting the decisions made about locating pharmacies in pursuit of unique market niche, level of purchasing power, long-term social and economic stability,^[29] as well as factors associated with market entry and exit.^[30] Because low-income neighborhoods and neighborhoods of color, in general, have been less preferred by investors, including pharmacies, we expect that, despite significant population density in these areas, we will see negative associations between pharmacy accessibility and both poverty and percent Black residents. This expectation is also based on the extant literature in pharmacy accessibility. A study of geographic access to neighborhood pharmacies and medications in New York City^[31] indicated that there was a significant difference in density of smaller, independent pharmacies with very limited stock and hours of operation, and larger, chain pharmacies in poor communities as compared to the middle and low-poverty communities. More pharmacy ‘deserts’ were disproportionately found to be in low-income communities and in segregated Black and Hispanic communities.^[15] In Baton Rouge, investigators found a negative association between percent Black population and their 2SFCA pharmacy access measure.^[18]

Associations between pharmacy accessibility measures and selected socio-demographics are calculated using Spearman’s rank-order correlation due to the skewness of the accessibility measures and selected census variables.

Data sources and variables

Pharmacy locations are extracted from InfoUSAs business 2016 database using the primary SIC code ‘591205’ (including compounding and non-dispensing pharmacies) and geocoded. Population locations are represented by the population-weighted mean centers derived from 2010 census tract boundary. StreetMap data in 2013 from ESRI is used to enable distance calculations. Data for socio-demographic variables are the 2010–2014 American Community Survey.^[32]

Study area

Taking advantage of our prior knowledge about local places, we evaluated the effectiveness of the new UR-2SFCA method in southeastern Wisconsin, which is the most developed area within the state. Milwaukee, the most populous county in the state, has been one of the most segregated US cities for years.^[33] The African American population is concentrated on the north side of the city, and the Hispanic population is located on the south side, while other parts of the region are dominated by the white/Caucasian population. Southeastern WI is an ideal area in which to test the new spatial method as it has known spatial patterns of disparity in several other demographic and socioeconomic characteristics, including vehicle ownership per household and poverty. As illustrated in the quantile map of population density (Figure 1a), the most densely populated areas are within the city limits of Milwaukee, Racine and Kenosha and population density decreases from the city centers to further out. The pharmacies’ distribution does not mirror population density; rather, pharmacies are located primarily on the periphery of the city limits in suburban tracts, rather than within the highest density tracts within the city limits. (Figure 1b and c).

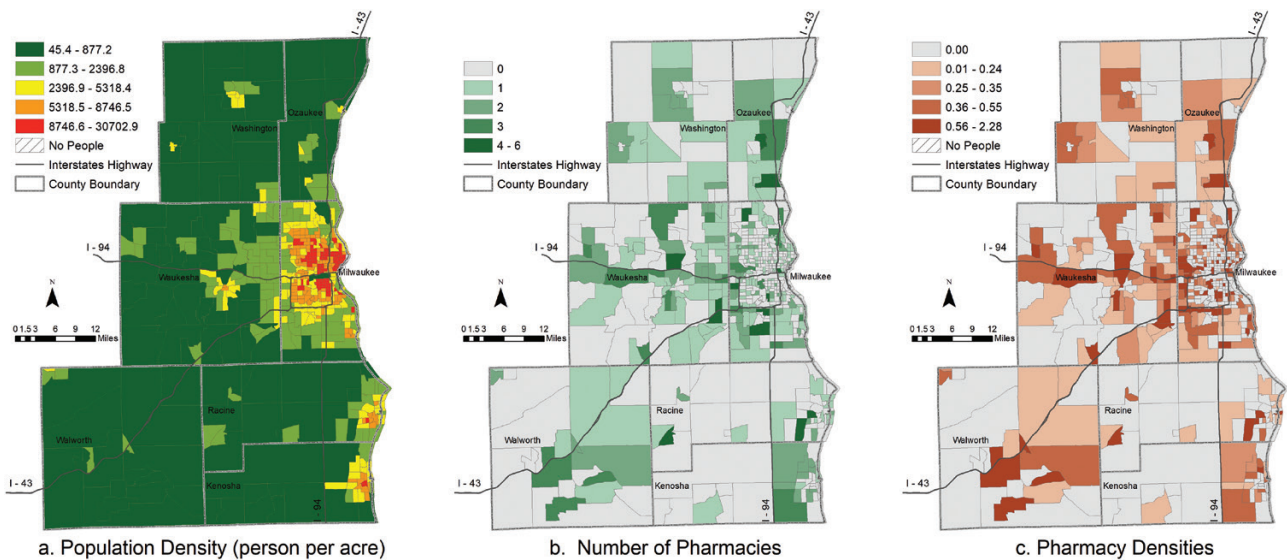


Figure 1 Maps of population distribution and pharmacies in Southeastern Wisconsin.

Table 1 Available measures for defining urban/suburban/rural in the US’ literature

Measures/source	Geography	Limitations
Population density	Any scale	Sensitive to the area size; need to be classified into categories
US census urban/ rural	Block	No suburban category
Percent of urban population	Tract	Derived from block-level urban/rural classes; need to be classified into categories
Rural-urban commuting area codes (RUCA)	Tract	Need to be reclassified from ten primary codes to three categories
Urban/rural from food desert research atlas	Tract	No suburban category
CMS	ZIP code	Unclear generalizability to finer geography
greatdata.com	ZIP code	Unclear generalizability to finer geography

Definitions of urban, suburban and rural tracts

To classify census tracts into urban, suburban or rural areas, we compared the existing definitions of urban and rural^[34] and their limitations for our purpose (Table 1). They either lack the category for suburban areas (such as the urban/rural tracts defined by Food Desert Research Atlas and the urban/rural blocks defined by US census) or are only available at a much coarser level of geography (for example, the CMS classified ZIP codes into urban/suburban/rural categories). We mapped the measures that are (dis) aggregable to three levels (U/S/R) then validate their spatial distributions using our prior knowledge about local places as well as other reference information from the US census bureau. None of these approaches captured the variations in tracts sufficiently. For example, in Figure 2, the settlement pattern derived from the CMSs ZIP code-based density criteria (Figure 2c) was compared with the patterns of the urban/rural census blocks and the designated census places (Figure 2a and b). The map (Figure 2c) shows to some degree the urban–rural differences between places but not in as adequate granularity as the distribution of the urban and rural locales with which we are familiar.

Due to no desirable measures in Table 1, we developed a new measure for defining U/S/R tracts (Figure 2d), using very high-resolution block-level data in which urban and rural blocks are defined by the census bureau. Our approach is to first calculate the percent of the number of urban blocks for each tract with at least one resident, then to discretize the values of such a percent

variable into three groups, corresponding to U/S/R categories. Two cut points (77.5 and 30%) for the U/S/R classes were determined among all the tracts within metropolitan statistical areas (59,982 tracts) in the USA by the Jenks classification, which minimizes within-class differences and maximizes between-class differences.^[35] An urban tract has more than 77.5% urban blocks, while a rural tract has not greater than 30% urban blocks; a tract containing between 77.5 and 30% urban blocks is regarded as suburban. The resultant pattern of urban/suburban/rural tracts (Figure 2d) shows adequate variation while maintaining the similarities of places within the same class. To a large extent, the map from the new urban/suburban/rural measure reveals a more detailed distribution of urban/rural places, which is more similar to their actual distribution. A sensitivity analysis was conducted to explore two alternative sets of cut-points (90/60 and 95/75), both of which require tracts to have a higher proportion of urban blocks to be classified as urban or suburban than the cut points imposed by the Jenks approach.

Results

Figure 3 compares the spatial distribution of accessibility scores in the study area using each of the three fixed catchment sizes (panels a, b and c) and the proposed UR-2SFCA approach (panel d). In all accessibility maps, darker colors (smaller values) indicate poorer access, and lighter colors (larger values) indicate better access.

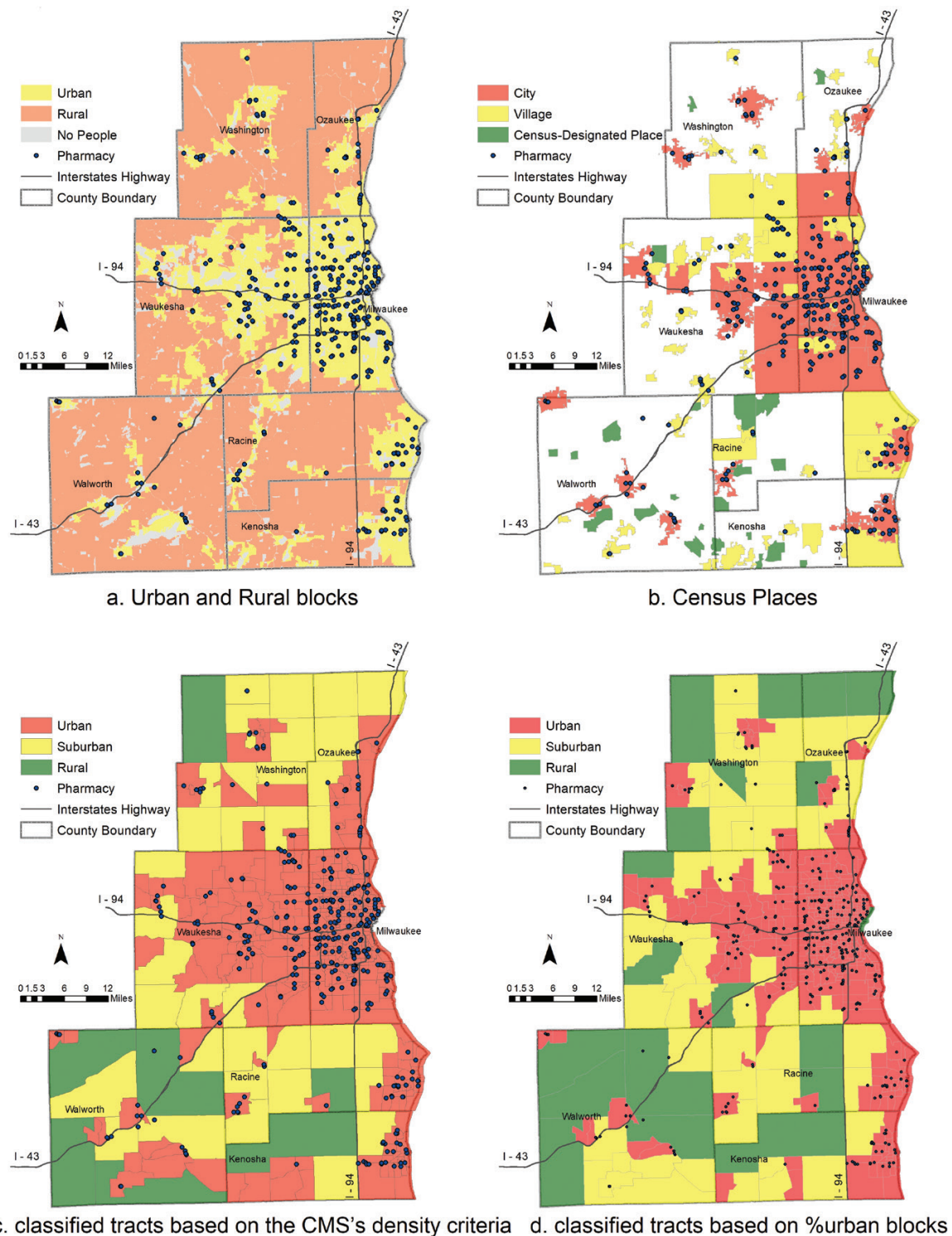


Figure 2 Maps of census blocks, census places, and classified census tracts.

Measuring pharmacy access

The maps reveal an inconsistent definition of spatial accessibility, depending on the method used. The traditional 2-mile measure (Figure 3a) shows that the central city of Milwaukee has the poorest access, likely attributed to the dense urban population residing there. Much of the study area, which is comprised largely of suburban or rural areas, have no access to any pharmacy because

the 2-mile distance employed is shorter than is common in these areas. We argue that this is not a true lack of access, as residents in these areas are more likely than their urban counterparts to be willing and able to travel a distance longer than 2 miles by car to access a pharmacy. Thus, when using a 2-mile catchment size, inaccessibility to pharmacies in more rural areas is likely to be overstated.

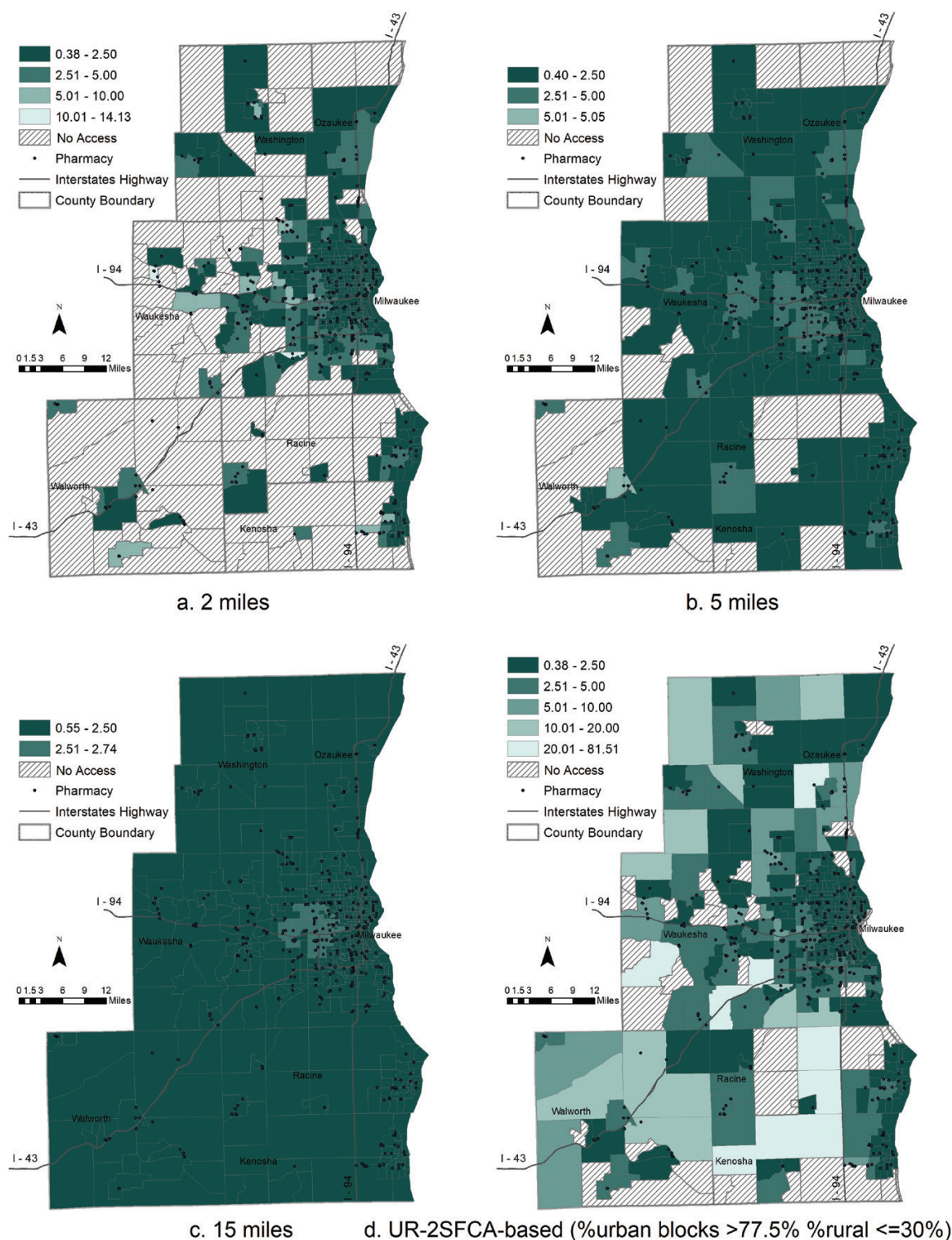


Figure 3 Maps of 2SFCa pharmacy accessibility using fixed catchment sizes (2-, 5-, and 15-miles) and UR-2SFCa pharmacy accessibility.

With an increase in the fixed catchment sizes (comparing Figure 3b and c with Figure 3a), more tracts become accessible, but the range of the accessibility scores becomes narrower, and the spatial variation in pharmacy accessibility diminishes gradually, resulting in a lack of variation in spatial accessibility measured overall. This is especially evident when the 15-mile catchment size is applied,

showing similar accessibility scores in most of the study area. The use of a larger catchment size has an effect of smoothing out accessibility scores, which artificially reduces the variation in pharmacy access across the study area.

In contrast, the results of the UR-2SFCa method (panel d) can be compared to the original 'one size fits all' approach (panels a, b and

c). As illustrated in panel d, the areas that are more rural and located between the towns/villages and the cities (for example, the majority of Walworth County in the southwest of the study area, or the west side of Kenosha County) are assigned an accessibility score, compared to their inaccessible status when one smaller single catchment size is used for estimation (panel a and b). This reflects the reality that residents in those areas can still use pharmacy services that are available within a distance to which rural residents are likely accustomed to traveling by car.

There are still some tracts identified as inaccessible using the UR-2SFCA method, for example, the areas located along the southern border of the region, which is the border with the state of Illinois. Of note, because the pharmacies from the counties and states bordering the study area were included in the calculation, there is no concern for an edge effect. Those tracts are more likely to truly lack access to pharmacies based on the CMS expectations of pharmacy access within 2-, 5- and 15-miles depending on urban/suburban/rural status. Compared with the 5- or 15-mile-based accessibility map, the map of the UR-2SFCA-based accessibility preserves more spatial variation in the accessibility score. It reveals more granular changes in pharmacy access when traveling across Southeastern Wisconsin.

Association between pharmacy access and population characteristics

Figure 4 illustrates the spatial distribution of the selected socio-demographic factors by tract. The spearman correlations relating the three 2SFCA and UR-2SFCA measures with the selected census variables are reported in Table 2. The majority of the correlations are significant, except the ones between the 2- or 5-mile-based measures

and poverty or percent black. The UR-2SFCA measure has the highest correlations with all the census variables, and all correlations are in the expected direction. In contrast, the 2- and 5-mile-based original measures have opposite correlations with household poverty. This suggests that using one constant threshold across urban and rural places is problematic. The misrepresentation of accessibility for the suburban or rural tracts may completely change the relationships being investigated, leading to opposite conclusions. The correlations for the 15-mile-based measures always have opposite signs compared to the other measures, which do not make sense and imply that 15-mile is certainly not an appropriate catchment size for measuring pharmacy accessibility in the study area.

Discussion

The UR-2SFCA method yielded higher access on average, and the UR-2SFCA-based accessibility had the highest correlations with the selected socioeconomic variables. The introduction of the different catchment sizes varying by the urban/suburban/rural classification of pharmacy and population locations resulted in more granular variations in accessibility scores and fewer areas classified as having 'no access.' Comparing the results with those from three fixed-size measures, the urban-rural disparity in access to pharmacies is reduced after applying larger catchment sizes to the suburban and the rural areas into the calculation.

This has important policy implications. First, when the goal is to direct limited funds to the areas with the highest needs, our study supports the argument that need can be measured in a way that accounts for differences between urban and rural areas. For Southeastern

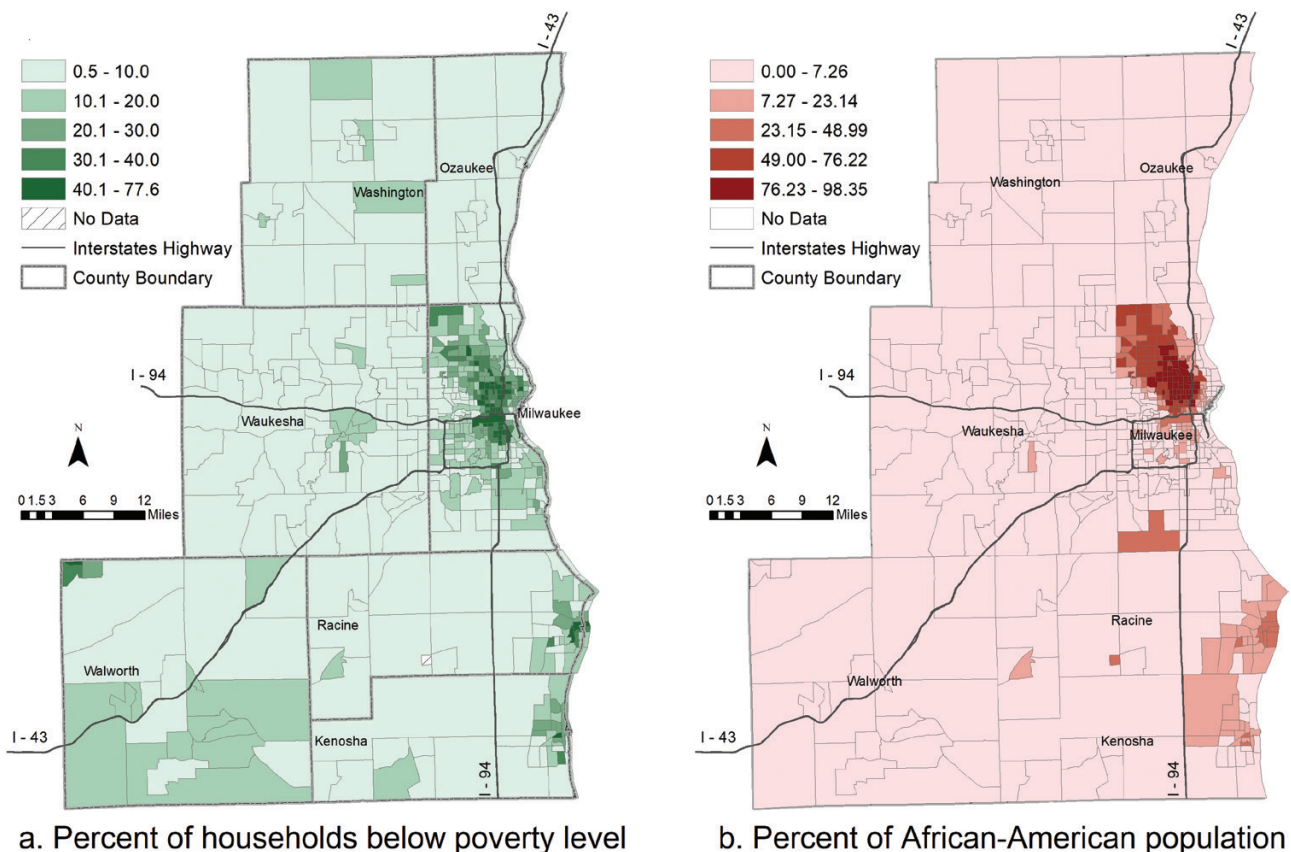


Figure 4 Maps of socioeconomic variables.

Table 2 Spearman correlations between various 2SFCA measures and census variables

Measures	Thresholds	Observations with a zero score (that is, 'no access') (n)	Households Below Poverty (%)	African-American Population (%)
UR-2SFCA	77.5/30	36	-0.186*	-0.247*
2SFCA	2 miles	77	0.038	-0.039
	5 miles	20	0.030	-0.066
	15 miles	0	0.341*	0.407*

Note: *Indicates the significance at 0.05 level.

Wisconsin, all maps are consistent in their findings suggesting the poorest access in several central cities including Milwaukee, Racine and Kenosha. However, even with the new measure, there are still persistent disparities in pharmacy access for the northern areas (which are relatively rural) in the study area. These areas may also benefit from dedicated resources to overcome some of the observed access barrier to pharmacies. Second, this research supports CMSs population density-based regulations for managed care and prescription drug plans.

The evaluation based on the correlation analyses illustrates that the original 2SFCA method will not perform well when the distance threshold specified is relatively large (15 miles in this case). The smaller catchment (2 miles) seems less appropriate than the other (5 miles), given that the smaller size yielded more tracts with no pharmacy access and not significant correlations. Considering all together with the details in the spatial patterns revealed, the 'no access' areas, and the correlations with the possible explanatory variables, the pharmacy index calculated using the UR-2SFCA method exhibits the greatest validity for assessing region-wide pharmacy accessibility.

The spatial patterns of UR-2SFCA pharmacy access calculated using different schemas are the same or similar for the very populated areas such as the cities, while small differences are observed in a few suburban and rural areas. Their associations with the socioeconomic variables are all higher than the scenarios of a fixed catchment size, although the most urbanicity-restricted scenario (the 95/75 scheme) has the highest correlations with socioeconomic variables.

This study is not without its limitations. First, the specific parameterization of the model is dependent on several key inputs, including CMS criteria and census classification of urban/rural blocks. If CMS or the US Census Bureau update their regulations or definitions, the actual value of accessibility scores would need to be re-evaluated. Second, the assumption of equal capacities across all pharmacies can be eliminated, if detailed information about the number of licensed pharmacists, staff and/or opening hours of pharmacies is available. The third limitation is that the results of the case study may not be always generalizable to other MSAs in the USA. Fourth, no subjective measure of pharmacy accessibility is available for validating the UR-2SFCA-based accessibility scores, which may not be consistent with patients' actual perceived access or utilization of pharmacies.

Conclusions

In this study, an adapted 2SFCA method designed to enhance pharmacy accessibility estimates in a study area with a mix of urban, suburban and rural settings is developed and evaluated. The case study clearly indicates the need for incorporating urban-rural differences

into a 2SFCA framework when assessing spatial accessibility of pharmacies. The performance of different accessibility measures was compared by their associations with potentially relevant variables (socio-demographic ones and/or disease outcomes). If applied nation-wide, the proposed measure could support accessibility studies with small area (tract) detail at the national level. Future work is needed to test and enhance UR-2SFCA measure proposed in this study. Future developments might include adding a distance decay function or other adaptations and testing the measure against health outcomes related to pharmacy access.

Authors' contributions

Yuhong Zhou conceptualized and implemented the method, performed the correlation analysis, and wrote the manuscript. Kirsten M. M. Beyer contributed to the conceptualization of the method, the writing of the manuscript, and the supervision of the whole process. Purushottam W. Laud provided supervision to the analytical part, helped with the interpretation of the results, and reviewed and edited the manuscript. Aaron N. Winn provided consultation and reviewed and edited the manuscript. Liliana E. Pezzin and Ann B. Nattinger contributed to the reviewing and editing of the manuscript. Joan Neuner supported the investigation through her funded grant, contributed to the writing and revising of the manuscript, administered the project and provided supervision.

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Conflict of Interest

None declared.

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