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QUANTITATIVE RESEARCH

Geographic disparities in accessing community pharmacies among vulnerable populations in the Greater Toronto Area

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Abstract

Objectives Geographic accessibility to community pharmacies (CPs) plays an increasingly important role for the well-being of a community. This study examines the geographic distribution of CPs within the Greater Toronto Area (GTA) relative to the residential patterns of vulnerable populations, including older adults (65+ years), infants and children (0–9 years), and low-income households.

Methods The study develops a geographic accessibility index at a dissemination area (DA) level by employing the enhanced two-step floating catchment area (E2SFCA) method to measure geographic accessibility to pharmacies. A vulnerability index is also developed to assess and visualize the residential patterns of vulnerable groups. A combined vulnerability-accessibility index is then constructed to identify low-access areas associated with high levels of socio-economic vulnerability. A range of geo-referenced datasets are analyzed within a geographical information system.

Results The study reveals geographical disparities in accessing pharmacies between urban and suburban areas and across different neighbourhoods, while accounting for population density and distance decay. About 19% of the population (or 15% of DAs) are under-serviced, with very poor geographic access to CPs (1.7 CPs per 10,000 persons), compared to 29.6% of the DAs that are well-/over-serviced, with an average score of 2.8 CPs per 10,000 persons.

Conclusion The spatial-quantitative analysis at a small geography (DA) allows for improved accuracy for identifying specific neighbourhoods that are in need of greater access to pharmacies by vulnerable residents and areas that have an excessive supply of pharmacies. It provides implications for addressing barriers to accessing pharmacies among high-needs groups, including the rapidly growing older adult population in the GTA.

Résumé

Objectifs L'accessibilité géographique aux pharmacies communautaires (PC) joue un rôle de plus en plus important pour le bien-être d'un quartier. Notre étude porte sur la distribution géographique des PC dans la région du Grand Toronto par rapport à la répartition par quartiers des populations vulnérables, soit les personnes âgées (65 ans et plus), les nourrissons et les enfants (0 à 9 ans) et les ménages à faible revenu.

Méthode Un « indice d'accessibilité géographique » est élaboré au niveau de l'aire de diffusion (AD) en employant la méthode améliorée des aires d'attraction flottantes à deux étapes (E2SFCA) pour mesurer l'accessibilité géographique aux pharmacies. Un « indice de vulnérabilité » est également élaboré pour évaluer et visualiser la répartition des groupes vulnérables par quartiers. Un « indice combiné de vulnérabilité et d'accessibilité » est ensuite construit pour cerner les aires à faible accès associées à des niveaux élevés de vulnérabilité socioéconomique. Des jeux de données géoréférencés sont analysés au moyen d'un système d'information géographique.

Résultats L'étude révèle des disparités géographiques entre les aires urbaines et suburbaines et entre différents quartiers dans l'accès aux pharmacies, tout en tenant compte de la densité de population et de la courbe de fréquentation en fonction de la distance. Environ 19 % des habitants (ou 15 % des AD) sont mal desservis et ont un accès géographique très limité aux PC (1,7 PC

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pour 10 000 personnes), alors que 29,6 % des AD sont très/excessivement bien desservies, avec un indice moyen de 2,8 PC pour 10 000 personnes.
Conclusion L'analyse spatio-quantitative à petite échelle géographique (celle des AD) permet une précision améliorée dans le repérage des quartiers où les résidents vulnérables auraient besoin d'un meilleur accès aux pharmacies, et des aires où l'offre de pharmacies est surabondante. Nous en tirons des conséquences pour aborder les obstacles à l'accès aux pharmacies chez les groupes aux besoins élevés, notamment la population en croissance rapide des personnes âgées dans la région du Grand Toronto.

Keywords Community pharmacy · Geographic accessibility · Vulnerable populations · Greater Toronto Area

Mots-clés Pharmacie communautaire · Accessibilité géographique · Populations vulnérables · Région du Grand Toronto

Introduction

Community pharmacies (CPs) play an important role in healthcare delivery for communities in Canada and other countries. Pharmacists are increasingly being recognized as an important part of a primary healthcare team by Health Canada, since they provide key services associated with medication management, such as dispensing and renewal, and related services and counseling, such as smoking cessation and cardiovascular screening (Agomo 2012; Kennie-Kaulbach et al. 2012; Hughes et al. 2017). They assess the suitability of medication for patients, taking into account a patient's medical history, as well as possible side effects and interaction with other drugs. Many chain pharmacies also deliver preventive services, such as administering immunizations and influenza vaccines (Shah 2010; Papastergiou et al. 2016). In some Canadian provinces, pharmacies have been granted an expanded scope of practices, including various prescribing privileges, and are managing patients with a higher prevalence of chronic diseases and acute conditions (Papastergiou et al. 2016; Tannenbaum and Tsuyuki 2013). CPs are usually conveniently located in community settings such as malls and plazas, with extended working hours and walk-in policies, and therefore are uniquely positioned to address some of the structural barriers in healthcare access, particularly those related to hours of service, availability of appointments, and transportation/proximity (Papastergiou et al. 2016; Buchan et al. 2017; Horsfield et al. 2014; Goad et al. 2013). Given the increasing burden of chronic conditions on the Canadian population and the resulting demand for primary healthcare, pharmacists are playing a growing part in relieving pressure on other primary healthcare professionals and help to alleviate wait times (Hughes et al. 2017; Canadian Pharmacist Association 2013).

Studies show that healthcare use and disease burden increase as the distance between home and primary care physicians increases (Billi et al. 2007). Such an inverse relationship between geographic access and utilization has also been observed in accessing and using community pharmacies (Lluch and Kanavos 2010; Norris et al. 2014; Hussainy et al. 2015; Rushworth et al. 2017). While CPs are regarded as the "most accessible health resources to the general population" due to their large numbers, broad geographic distribution in urban and rural areas, and extended hours of operation (Lin 2004), they are not distributed evenly in space, resulting in underserviced neighbourhoods, or "pharmacy deserts," in socioeconomically disadvantaged neighbourhoods (Qato and Lambert 2014). Previous studies have revealed disparities in geographic accessibility to pharmacies, for example, among the elderly population living in rural areas in the US (Lin 2004; Casey et al. 2008; Ikram et al. 2015). A study conducted in New Zealand found that patients farther from a pharmacy are less likely to use pharmacy services (Hiscock et al. 2008). In another Australia-based study, increased distance to pharmacies reduced participation in chlamydia screening provided by community pharmacies (Parker et al. 2015). There is a dearth of knowledge in Canada on the spatial distribution of CPs and the extent to which CPs provide spatially equitable services to vulnerable and relatively isolated populations.

The importance of geographic accessibility in healthcare has been addressed in a much more extensive body of literature focusing on primary care physicians and hospitals (Hiscock et al. 2008; Arcury et al. 2005; McGrail 2012). Canadian studies have explored disparities in the distribution of and geographic access to family physicians, physiotherapists, and dentists in various urban, rural, and provincial settings (Schuurman et al. 2010; Bath et al. 2015; Emami et al. 2016; Wang 2007). "Geographic accessibility," or "spatial accessibility" (terms used interchangeably in the literature), refers to the relative ease with which individuals from one location can reach other specified zones or point locations, and can be measured by geographical models such as the two-step floating catchment area model and its variations (Wang 2007; Luo and Wang 2003; Luo and Qi 2009; Ngui and Vanasse 2012; Cao et al. 2016; Donohoe et al. 2016; Dai and Wang 2011; Fransen et al. 2015; Lee and Hong 2013; Williams and Wang 2014; Wang and Tormala 2014). By using accessibility as an analytical framework, previous studies have systematically identified healthcare shortage areas, highlighting a spatial mismatch between the provision of healthcare services (e.g., hospitals, linguistically diverse family physicians) and the demand for such services (Wang 2007;

Luo and Wang 2003; Luo and Qi 2009; Ngui and Vanasse 2012; Cao et al. 2016; Donohoe et al. 2016; Wang and Tormala 2014; Chateau et al. 2012). In comparison, geographic access to CPs is vastly under-studied in Canada, despite the important role CPs play in providing essential health services to vulnerable and rapidly aging populations. According to the 2016 census, 17% of Canada's population is aged 65 or older, compared to 7.6% in 1961, and for the first time, the population of older adults has surpassed that of children (aged 0–14 years). Older adults, as well as infants and children, have an increased vulnerability to diseases, tend to use more medications, and have more frequent interactions with pharmacies (Health Canada 2001). Income is generally regarded as one of the most important social determinants of health. People who have a low income are more likely to have a lower health status, as measured by self-reported health or functional diseases (Toronto Public Health 2015), and possibly an additional challenge in accessing pharmacies due to a lack of transportation (i.e., they likely do not own a car).

This study seeks to examine the distribution of CPs within the Greater Toronto Area (GTA) in relation to the residential patterns of vulnerable populations, including older adults, infants and children under the age of 10, and low-income households. The objectives of this study are as follows: (1) measure geographic accessibility to CPs by calculating and mapping a geographic accessibility index for the GTA at a small and detailed spatial scale—DA (dissemination area); (2) develop a vulnerability index to assess and visualize the residential patterns of vulnerable groups with a high need for CPs; and (3) identify under-serviced neighbourhoods with a high level of vulnerability and poor geographic access to CPs. The GTA is the most populous metropolitan area in Canada, with a mix of large urban centres and smaller suburban and urban-rural fringe communities. According to the 2011 National Household Survey, the GTA has a population of 6,054,191, which is 18% of Canada's population and 47% of Ontario's population. Among the GTA population, 14.4% are older adults (aged 65 +), 11.5% are infants and children under the age of 10, and about 19.7% are below the low-income cutoff. Over time, the GTA has experienced extensive population growth and suburbanization, with marked distinctions in population density, socio-economic status, and the availability of essential services across different urban and suburban neighbourhoods. Increasing economic polarization among Toronto neighbourhoods has also been documented (Hulchanski 2010). Neighbourhoods near the city core in Toronto are associated with the highest accessibility to family physicians (Wang 2007), while the low-density and car-centric geography of the outer suburbs creates a significant challenge for low-income residents with respect to accessing community services due to limited social and income resources (Lo et al. 2015). It is within the context of the dynamic socio-economic demographics of the GTA that this study is conducted, in order to understand the geographic access to CPs of vulnerable populations with a high need for pharmacy services.

Data and methods

The dataset on CPs located in the GTA was obtained from the IMS Brogan database (2014), which provides information on the address and name of pharmacies of major banners such as Shoppers, Pharma Plus, and IDA; pharmacies located inside grocery stores and supermarkets, such as The Drugstore Pharmacy; and local pharmacies or independents. The CPs were geocoded based on street addresses. The socio-economic and demographic characteristics of populations were drawn from the 2011 CensusPlus, an enhanced geo-referenced census database that incorporates the National Household Survey. Three variables were extracted from CensusPlus at a DA level: population (65+ years), population (0–9 years), and average household income. They were the basis for developing a vulnerability index at the DA level that highlights the geographic inequality in demand for CPs collectively from older adults, children, and low-income households. These three demographic groups tend to be vulnerable to diseases due to their age and socio-economic status, and require more interaction with CPs, yet are faced with numerous access barriers associated with declining health and mobility (for example, among older adults) and lack of transportation (for example, among low-income households). The street network data were extracted from the TomTom MultiNet dataset (2014), which gives the average speed and length of each road segment in the GTA. These data enable the calculation of travel time along a street network in order to model the geographic accessibility to CPs. Travel time is regarded as a more realistic measure of spatial separation between the locations of CPs and a population's residence, compared to distance (street network-based or straight line), which does not consider speed limit. The dataset also considers one-way roads when calculating travel time, but it does not take into account traffic.

The main geographic model used in this study is the enhanced two-step floating catchment area (E2SFCA) method to measure geographic accessibility to CPs, implemented in a geographical information system (GIS). The E2SFCA model considers three datasets as input: point locations representing *supply* (e.g., geocoded CPs), point locations representing *demand* (e.g., population associated with census tract centroids), and *travel networks* that depict the pathways allowing populations to travel to CP locations. The model calculates geographic accessibility as ratio of potential demand to supply of CPs by taking into consideration various travel zones based on travel time. The E2SFCA model and its variations have been used widely as a reliable measure of geographic accessibility to service providers (Wang 2007; Luo and Wang 2003; Luo and Qi 2009; Ngui and Vanasse 2012; Cao et al. 2016; Donohoe et al. 2016; Dai and Wang 2011; Fransen et al. 2015; Lee and Hong 2013; Williams and Wang 2014; Wang and Tormala 2014). They have been used to examine the geographic accessibility of immigrants to culturally diverse family physicians and to quantify spatial access to mental health facilities in a Canadian urban context (Wang 2007; Ngui and Vanasse 2012). In studies in the US, these models have been employed to analyze spatial access to pharmacies (Ikram et al. 2015), primary care physicians (McGrail 2012; Luo and Wang 2003; Luo and Qi 2009), mammography centres (Donohoe et al. 2016), and organ transplant centres (Cao et al. 2016). Outside the realm of healthcare, these models have been successfully applied to explore geographic accessibility to food stores (Dai and Wang 2011), child daycare centres (Fransen et al. 2015), urban parks (Lee and Hong 2013), and high schools (Williams and Wang 2014) in different study areas (see Luo and Qi (2009) for a detailed explanation of the E2SFCA method, which consists of two major steps described in Eqs. 1 and 2).

$$R_j = S_j / \sum_{k\in\left(d_{kj}\le d_0\right)} P_k W_r = S_j / \left\{ \sum_{k\in\left(d_{kj}\le d_1\right)} P_k W_1 + \sum_{k\in\left(d_{kj}\le d_2\right)} P_k W_1 + \sum_{k\in\left(d_{kj}\le d_3\right)} P_k W_1 \right\} \quad (1)$$

$$A_i^F = \sum_{j\in\left(d_{ij}\le d_0\right)} R_j = \left\{ \sum_{j\in\left(d_{ij}\le d_1\right)} R_j + \sum_{j\in\left(d_{ij}\le d_2\right)} R_j + \sum_{j\in\left(d_{ij}\le d_3\right)} R_j \right\} \quad (2)$$

where A_i^F is the calculated accessibility at DA i to pharmacies, d_{ij} is the street network-based travel time between i and j, S_j is the number of pharmacies at j, and P_k is the population that falls within the service area of a pharmacy location. In *step one*, for each pharmacy location, pharmacy-to-population ratio R_i is computed for DA centroids that fall within the pharmacy service area. R_j reflects the degree of competitiveness for pharmacies. In *step two*, for each DA centroid, all R_j associated with all pharmacy locations within the travel threshold of a DA centroid are summed up to compute the geographic accessibility index at a DA level. Three separate travel time zones are incorporated, 0 to 5 (d_1), 5 to 10 (d_2) and 10 to 15 (d_3) min, in order to account for distance decay as nearby pharmacies are deemed more accessible.

Using the Gaussian function, the three travel time zones translate to three different weights $W_{1\text{–}3}$ (1.00, 0.42, 0.09), with greater weights assigned to nearer pharmacies. A study by Luo and Qi (2009) used a 10-min interval for different travel time zones when using an ESFCA model to measure spatial accessibility to primary care physicians, and suggested a sharper distance decay for access to pharmacies, hence the use of a 5-min interval and the weights selected for this study. Geographical accessibility scores are further standardized by using the z-score, expressed in terms of standard deviations from their means, where the mean is given a value of 0, using the same approach as the previous studies mentioned (Wang and Tormala 2014; Frank et al. 2009; Wang 2018). The standardized z-scores allow for a geographic accessibility index to be created by classifying DAs into three groups—"High," "Medium," and "Low"—representing different levels of geographic access to community pharmacies based on their respective z-score (≥ 1, $(1, -1)$, ≤ -1), roughly cutting the 84 and 16 percentiles of the z-scores. This process transforms calculated geographic accessibility scores (as a continuous variable) to a geographic accessibility index (as a categorical variable) based on accessibility z-scores (Wang and Tormala 2014; Frank et al. 2009; Wang 2018), providing a more intuitive understanding of the level of geographic access to CPs for a given DA relative to other DAs in the GTA.

A vulnerability index is created at a DA level using the approach in Wang and Tormala (2014). First, z-scores are calculated for all three select census variables. Cutoff points are then determined based on − 1 std dev of average household income ($39,689), + 1 std dev for percentage of population (0–9 years) (i.e., 7%), and + 1 std dev for percentage of population (65+ years) (i.e., 22.3%). Then, a score of 1 is assigned to a DA if the z-score is greater than + 1 for the income variable, and lower than − 1 for the children and seniors variables. A DA is classified as "High" vulnerability if it is assigned a score of 1 for two or three variables, as "Medium" if it is assigned a score of 1 for one variable only, and "Low" if no variables fall under any of the cutoff points. For example, a "High" vulnerability DA can have an average household income below $39,689, a senior population over 22.3%, and a share of infants and children over 7%. "High" vulnerability DAs are likely to be associated with a relatively lower health status among their residents and thus with a high need for pharmacies and healthcare services in general. In contrast, "Low" vulnerability DAs are associated with a higher socio-economic status among their residents, and fewer barriers to accessing pharmacies and other health services. The vulnerability index and the geographic accessibility index are combined to highlight any spatial mismatch or discordance between CP access and neighbourhood (i.e., DA) conditions. For example, "High vulnerability-Low accessibility" areas can be identified from the combined index, where there is a high percentage of vulnerable populations with a high need for CPs, but where geographic accessibility to CPs is poor.

Results

In total, there are 1577 geocoded CPs in the GTA, representing 49% of the CPs in Ontario and 20% in Canada.

In the geocoding process, a small number of CPs (Wang 2018) in the GTA had address errors. They were geocoded manually after verifying individual store information from company websites. Table 1 summarizes the distribution of CPs across different census subdivisions (CSDs) in the GTA in relation to the residential patterns of high-needs groups. About half of the CPs in the GTA (50.2%) are located in the City of Toronto, which has 43.2% of the GTA's total population, 48.7% of its older population, and 38.7% of its children. Scarborough and North York have the highest shares of older adults in the GTA with lower than average household income. Proportionally, fewer CPs are located in the suburbs where there are more young children. Altogether, the four CSDs (Scarborough, North York, Toronto, Mississauga) have 62% of the CPs in the GTA, serving 76% of the total population. A certain degree of spatial mismatch is present in North York, which has the highest share of older adults in the GTA (13.4%) but a smaller share of CPs (10.5%). An overrepresentation of young children is present in Brampton (10.9%) and Vaughan (5.5%), relative to the shares of CPs and total population in the two CSDs. The Toronto CSD (city core) has an overrepresentation of CPs (17.9%) compared to its shares of older adults (11.5%) and children (8.9%).

Figure 1 provides a detailed geo-visualization of the calculated E2SFCA accessibility scores at a DA level, a fine spatial scale for revealing geographical differences in a metropolitan area. Generally, geographic accessibility to CPs decreases as the distance increases from the city core to the outer suburbs. Clusters of high accessibility are located in the city core, the inner suburbs (e.g., Scarborough, the western part of North York) and the outer skirts (e.g., Mississauga, Newmarket). The DAs are further classified into three categories to construct the geographic accessibility index representing "High," "Medium," and "Low" levels of access (Fig. 1 inset). A clear urban-rural difference is noted. The majority of DAs in the City of Toronto have "High" or "Medium" geographic accessibility to CPs. Two suburban CSDs (Newmarket, Aurora) have DAs with high accessibility (e.g., z-scores over + 1). A number of suburban DAs (e.g., in Vaughan, Richmond Hill, Markham, Ajax, and Brampton) and rural-urban fringe areas (e.g., Milton, Halton Halls, and Georgina) have "Low" geographic accessibility to CPs. Scores for DAs located near the edge of the GTA should be interpreted with caution due to the well-documented "edge effect," producing inaccurate scores in the E2SFCA model (Luo and Wang 2003; Wang 2014). These DAs can be problematic since the population

Table 1 Distribution of pharmacies and high-needs population by CSDs in GTA

CSD name	Total population (% in GTA)	No. of pharmacies (% in GTA)	Older adults (65+) (% in GTA)	Children (0–9) (% in GTA)	Average household income ($)
City of Toronto	43.2	50.2	48.7	38.7	$91,238
Scarborough	10.4	12.0	12.0	10.1	$70,871
North York	10.7	10.5	13.4	9.9	$89,532
Toronto	12.1	17.9	11.5	8.9	$107,123
Etobicoke	5.7	5.3	7.3	5.3	$95,381
East York	1.9	1.8	2.0	2.2	$88,000
York	2.3	2.6	2.5	2.3	$70,846
Suburbs	56.8	49.8	51.3	61.2	$104,310
Mississauga	11.8	11.6	10.5	11.8	$96,625
Brampton	8.7	6.2	6.1	10.9	$91,732
Markham	5.0	4.1	4.8	4.9	$110,654
Vaughan	4.8	4.5	4.2	5.5	$118,803
Richmond Hill	3.1	2.5	2.7	3.1	$106,168
Oakville	3.0	3.3	3.0	3.3	$142,266
Burlington	2.9	2.8	3.8	2.8	$107,255
Oshawa	2.5	2.2	2.8	2.4	$78,789
Whitby	2.0	2.0	1.6	2.4	$106,705
Ajax	1.8	1.3	1.2	2.1	$103,101
Pickering	1.5	1.1	1.3	1.3	$108,954
Clarington	1.4	0.8	1.3	1.5	$96,302
Milton	1.4	1.2	0.8	2.2	$111,300
Newmarket	1.3	1.5	1.1	1.3	$105,073
Other CSDs	5.8	4.8	5.8	5.8	$112,883
GTA total	100% (6,054,191 persons)	100% (1577 CPs)	100% (773,725 persons)	100% (693,205 persons)	$98,374

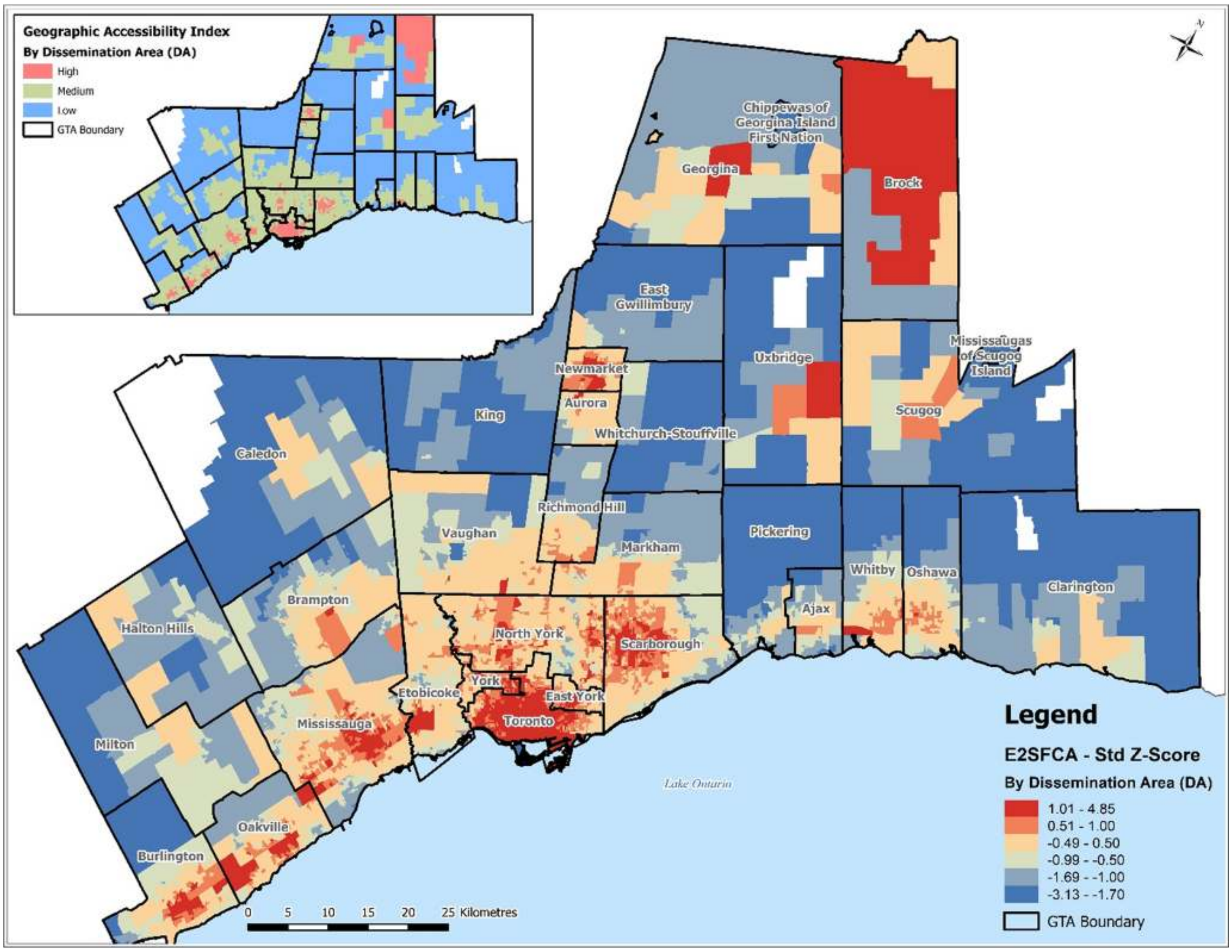

Fig. 1 Geographic accessibility (z-scores) to community pharmacies in the GTA (inset shows geographic accessibility index)

and CPs beyond the GTA boundary are not considered in the model. Many of these DAs (such as Brock) have large areas yet low population densities, and their high accessibility scores are likely biased due to the small number problem.

Figure 2 visualizes the vulnerability index created based on the three select census variables representing vulnerable populations in high need of services delivered by community pharmacies. The majority of the DAs in the GTA are classified as "Medium" vulnerability, which is associated with z-scores that fall within a wide range (i.e., 16 to 86 percentile). Approximately 10% of DAs are in the "High" vulnerability category, scattered across the City of Toronto and in some pockets in Burlington, Richmond Hill, and King. They are the most socio-economically and demographically disadvantaged DAs, with a high concentration of at least two vulnerable groups.

The geographic accessibility index and vulnerability index are integrated in Fig. 3 to identify any discordance between neighbourhood vulnerability and geographic accessibility to CPs. There is a spectrum of DAs of varying socio-economic conditions, age structures, and geographic accessibility to CPs across different neighbourhoods. Under-serviced areas include DAs of "High (vulnerability)-Low (accessibility)," "Medium-Low," and "High-Medium" values, representing a spatial mismatch between neighbourhood vulnerability and relatively poor geographic access to CPs. They are observed in several suburban and rural-urban fringe areas (e.g., Caledon, Vaughan, Markham, Brampton, Pickering, and areas north of Oakville, Burlington, and Stouffville), as well as in some of the city neighbourhoods, such as Milliken and Malvern in the eastern part of Scarborough, and Humbermede and Eringate-Centennial-West Deane in the western part of Etobicoke. The City of Toronto is divided into 140 neighbourhoods for social planning purposes. It should be noted that the term "neighbourhood" is used loosely in this paper when describing the socio-economic characteristics of a local environment (for example, neighbourhood vulnerability), whereas the official city neighbourhood names, such as Milliken and Malvern, are used to provide a spatial reference for clusters of DAs with different vulnerability-accessibility scores. As indicated in

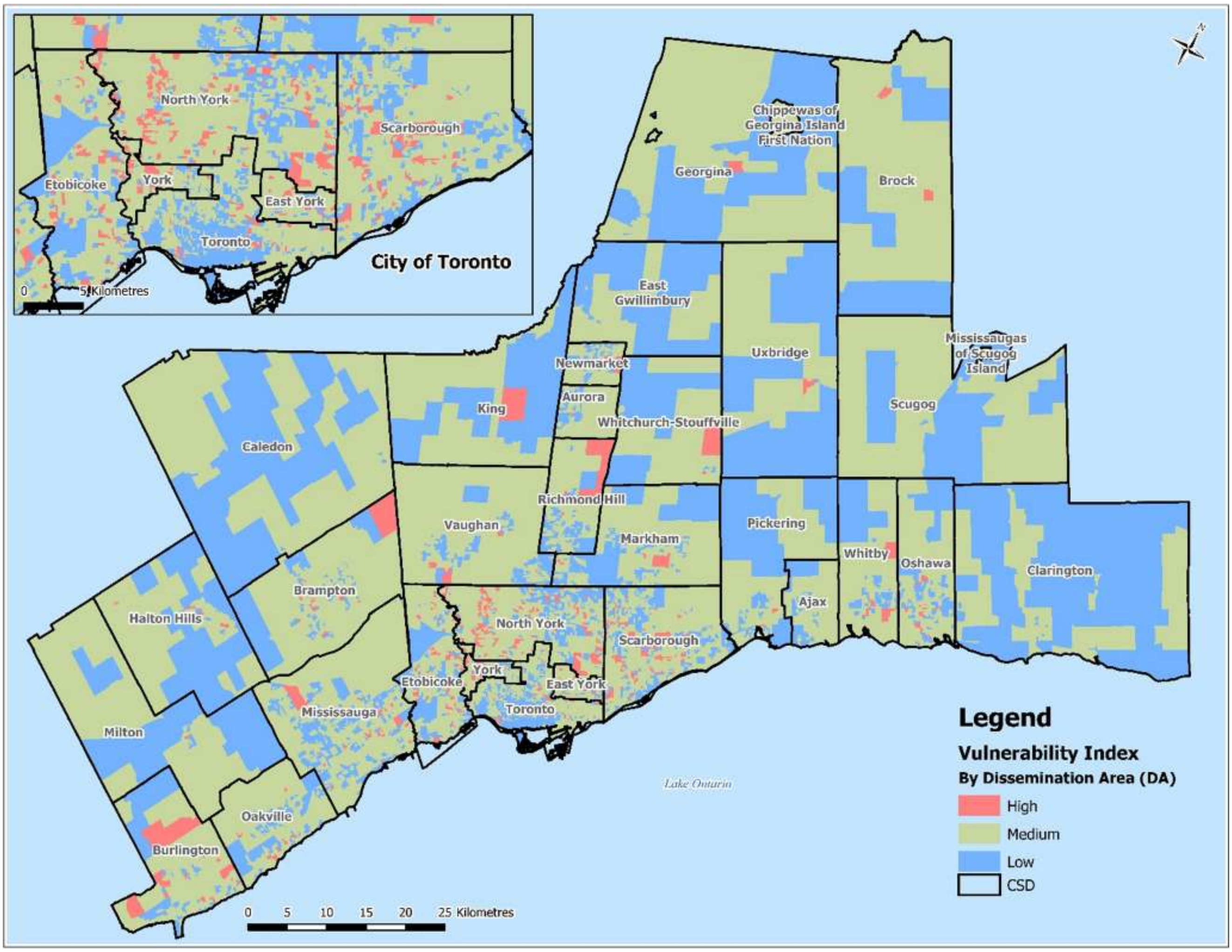

Fig. 2 Vulnerability index representing populations in high, medium, and low need of community pharmacies

Table 2, under-serviced DAs account for 15.3% of all the DAs and are associated with very poor geographic access to CPs, with scores ranging from 1.4 to 2.7 CPs per 10,000 persons. However, they are home to 16.8% of all the older adults and 24.9% of all the young children in the GTA. Among these under-serviced DAs, those with "Medium-Low" values have the lowest household income of $51,475, far below the GTA average of $98,372. Other under-serviced DAs are associated with household incomes above the GTA average.

A cluster of "Low-High" values are found in the downtown core, in areas such as Queen West, the Financial District, and the Distillery District, as well as the Waterfront communities with high-rise condominiums and apartment buildings. In sharp contrast to the under-serviced DAs, these areas are associated with "Low" vulnerability and "High" accessibility and are considered over-serviced by CPs. Most of them have a small share of young children and seniors. Some of them are within close proximity of a conglomeration of large hospitals and medical services in downtown Toronto, suggesting a location strategy for pharmacies to be close to major healthcare services. Other over-serviced and well-serviced DAs have "Medium-High" and "Low-Medium" values. They are spread out in various urban and suburban neighbourhoods in North York and south of Markham and Richmond Hill. Over-serviced and well-serviced DAs account for 29.6% of all the DAs in the GTA. Their accessibility scores are the highest, ranging from 2.6 to 4.1 CPs per 10,000 persons. In general, they are associated with a relatively higher average household income. About 55.2% of the DAs in the GTA are moderately serviced with "Medium-Medium" and "Low-Low" values, among which 52.1% have medium vulnerability and medium accessibility and are spread out in the City of Toronto, Vaughan, and south of Markham. In Table 2, there are both low- and high-income groups in the under- and well-/over-serviced categories, suggesting a need to examine the characteristics of specific DAs or neighbourhoods facilitated by detailed geo-visualizations. It should be noted that DAs of "Low-Medium" and "Medium-Low" values are

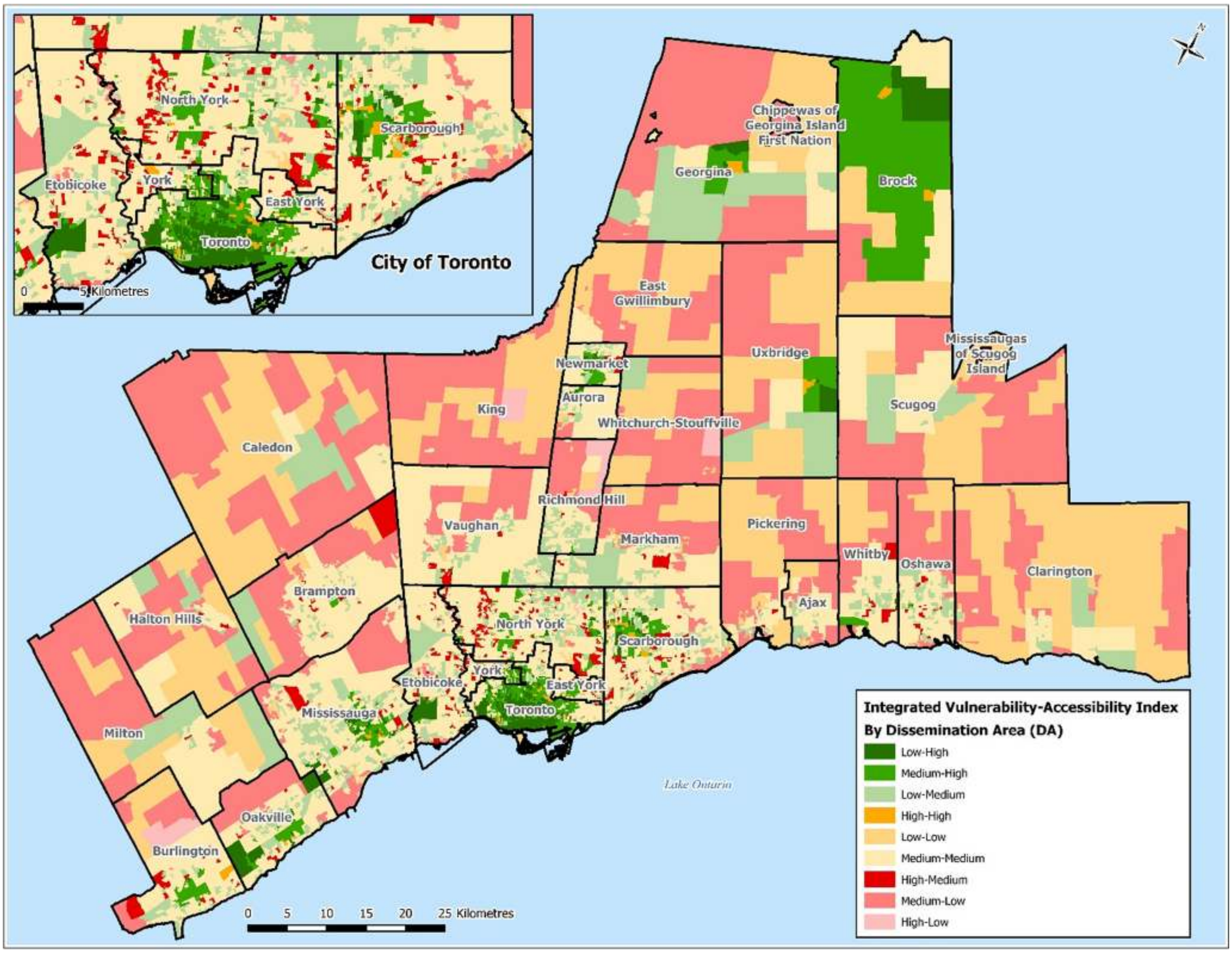

Fig. 3 Integrated vulnerability-accessibility index

classified as well-serviced and under-serviced areas, respectively. The former is associated with low vulnerability (or high income and low percentages of children and older adults) and medium (or above-low) geographic access to CPs. The latter

Table 2 Summary statistics of integrated vulnerability-accessibility index

Classification	Integrated vulnerability-accessibility index	No. of DAs	% DAs	Total population	% total population in GTA	Average accessibility scores (A^f_i/10,000)	% children in GTA	% older adults in GTA	Average household income ($)
Over-serviced	Low-High	438	5.4	324,147	5.4	4.1	2.6	4.5	87,134
Over-serviced	Medium-High	660	8.1	501,137	8.3	3.9	7.7	9.5	92,102
Well-serviced	Low-Medium	1232	15.1	748,634	12.4	2.6	7.6	13.8	107,796
Well-serviced	High-High	85	1.0	82,283	1.4	4	1.3	1.9	47,115
Moderately-serviced	Medium-Medium	4265	52.1	3,086,861	51.	2.6	54.5	51.3	100,276
Moderately-serviced	Low-Low	250	3.1	136,256	2.25	1.2	1.4	2.3	138,782
Under-serviced	High-Medium	338	4.1	296,649	4.9	2.7	5.5	7.0	51,471
Under-serviced	Medium-Low	908	11.1	872,350	14.41	1.4	19.3	9.6	114,955
Under-serviced	High-Low	11	0.1	5,873	0.1	1.4	0.1	0.2	114,868
	GTA total	8,187	100	6,054,191	100	2.6	100	100	98,372

indicates that DAs characterized by medium vulnerability are associated with a low (or below medium) level of geographic access to CPs.

The City of Toronto has a high population density and consists of diverse city neighbourhoods, ranging from very wealthy areas such as Forest Hill, Rosedale, and Casa Loma with a higher-than-average concentration of older adults, to low-income city neighbourhoods such as Jamestown, West Humber, and Regent Park. Despite the wide range of income and population demographics, the City of Toronto overall is associated with medium to high accessibility, as seen by the majority of "High-High" and "High-Medium" categories across the city. The "Low-Low" category accounts for only 3.1% of all DAs and 2.3% of the GTA's population. They are primarily located in peripheral, low-density, rural-urban fringe areas. Despite having a poor accessibility to CPs, the population residing in these areas has "low" vulnerability and a lower need for CPs, and therefore are not a major concern.

Discussion

Geographic accessibility to community pharmacies is highly relevant for the well-being of a community since community pharmacies are increasingly playing a vital role in healthcare provision and related services, such as consultation, immunization, health promotion, and screening. This pilot study systematically evaluated the location patterns of community pharmacies in relation to the distribution of older adults and other vulnerable groups in the Greater Toronto Area. Although the GTA is a very populous urban centre with a large number of community pharmacies, the number and accessibility of pharmacies varies across neighbourhoods with different socio-economic and demographic compositions. The first objective of this study was achieved by developing a geographic accessibility index that revealed a clear spatial disparity in accessing community pharmacies between the peripheral rural fringe and urban areas, and across different dissemination areas in the GTA, while accounting for population density and distance decay in accessing community pharmacies, by using the enhanced two-step floating catchment area (E2SFCA) model. DAs are the smallest standard geographic area for which all census data are disseminated, with a population of 400 to 700 persons. The DA-level geographic accessibility index allows for improved accuracy in identifying low-access neighbourhoods compared to using a larger geographical unit such as census tracts, which had been used in previous studies of geographic accessibility (Qato and Lambert 2014; Casey et al. 2008; Ikram et al. 2015; Ngui and Vanasse 2012).

To achieve the second objective, a vulnerability index was created to highlight the spatial distribution and clustering patterns of populations with a high need for community pharmacies, including older adults, young children, and low-income households in different Toronto neighbourhoods. Table 1 shows disproportionally large shares of older adults in North York and Scarborough with household incomes that are lower than the GTA average, and disproportionally more children living in Brampton and Vaughan. Since this vulnerability index simultaneously considers all three vulnerable populations, it allows for very effective visualization of "High" vulnerability DAs across the city and suburban areas.

The third objective, to identify under-serviced neighbourhoods with a high level of vulnerability and poor geographic access to community pharmacies, was successfully addressed by developing an integrated vulnerability-accessibility index. This index allows for a detailed visualization of where under-serviced, well-serviced, and over-serviced DAs are located with respect to access to community pharmacies. Overall, about 85% of the DAs (and population) in the GTA are moderately, well-, or over-serviced by community pharmacies. This suggests that the distribution of community pharmacies in the GTA overall provides relatively high levels of accessibility among the majority of the population, with an average score of 2.8 community pharmacies per 10,000 persons. The major areas of concern are the under-serviced DAs that fall within the "High-Low," "Medium-Low," and "High-Medium" categories. These areas have relatively high shares of populations in need of pharmacy services and have the potential for increased demand for and pressure on the existing pharmacies. East Scarborough, west Etobicoke, Caledon, Vaughan, Pickering, and areas north of Oakville, Burlington, and Stouffville are dominant examples of under-serviced areas. These DAs consist of approximately 19% of the GTA population and have an average accessibility score of 1.7 pharmacies per 10,000 persons (calculated from Table 2). These areas are important to note for future healthcare planning initiatives and the allocation of pharmacy services.

The merits of using the E2SFCA model and its variations in analyzing geographic access to healthcare services have been widely demonstrated (Wang 2007; Luo and Wang 2003; Luo and Qi 2009; Ngui and Vanasse 2012; Cao et al. 2016), including the ability of the model to consider not only distance to service location and destination attractiveness but also population distribution (e.g., demand and competition for services). Calculated accessibility scores highlight marked spatial variations in geographic access and therefore are a more meaningful indicator of spatial disparity in healthcare access, compared to a simple pharmacy-to-population ratio (e.g., 2.6 pharmacies per 10,000 persons for City of Toronto or the GTA). The E2SFCA model used in this study provides additional advantages by taking into account pharmacy service areas defined by different travel zones and access patterns defined by multiple distance decay weights. E2SFCA scores can be regarded as weighted physician-to-population ratios associated with a dissemination area, based on consideration of distance decay by travel time zone, and are straightforward to interpret and easy to implement. The combined vulnerability-accessibility index developed in this study is an appropriate and useful indicator of spatial equity in the delivery of pharmacy services to a diverse range of communities and neighbourhoods across the GTA. The small geographic analytical scale used in this study enabled us to pinpoint specific dissemination areas with vulnerable groups that are in need of greater access to community pharmacies, as well as dissemination areas that have an excessive supply of pharmacies. It should be noted that the vulnerability-accessibility index is a more suitable method than traditional spatial statistical analyses (e.g., Getis Ord Gi* statistics and local indicator of spatial autocorrelation) that may not capture isolated under-serviced dissemination areas surrounded by a large number of well-serviced dissemination areas because of the underlying statistical assumptions used in these techniques. It is of great importance to identify all low-access dissemination areas in order to understand the level of spatial discordance between the demand for and availability of pharmacies at a local scale.

This study provides a useful framework for developing an area-based vulnerability index for specific population groups in the context of accessing community pharmacies. Previous studies have developed and used different area-based socio-economic measures to characterize the socio-economic profile of a geographic area, based on a single component (such as neighbourhood income), or more commonly, multiple components (such as a deprivation index) (Denny and Davidson 2012; Matheson et al. 2012; Bell and Hayes 2012; Chateau et al. 2012). The contextual measure of neighbourhood socio-economic conditions is analyzed in relation to individual-level compositional characteristics in understanding health outcome and health disparities (Denny and Davidson 2012). Among the existing area-based socio-economic measures are the deprivation index from Canadian Marginalization Indices (2001, 2006) (CAN-Marg) (Matheson et al. 2012), Vancouver Area Neighbourhood Deprivation Index (VANDIX) (Bell and Hayes 2012), and the Socio-economic Factor Index (SEFI and SEFI-2) in Manitoba, Canada (Chateau et al. 2012), all of which are based on multiple census dimensions that are commonly regarded as social determinants of health and well-being. These measurements have been developed using statistical procedures, such as principal components factor analysis. Compared to these general area-based indices designed for health disparities research, the vulnerability index developed in this study, based on the three select variables (older age, young age, low household income), is a more specific area-based index since it highlights high, medium, and low areas in need of community pharmacies. It is a highly focused geographic index at the DA level based on the most recent census data (2011) available at the time of the study. Its specific scope, on the needs for and potential use of community pharmacies, offers intuitive insights and detailed spatial data and representations for stakeholders such as municipal planners, members of vulnerable groups, pharmacies, and public health policy makers. By simply changing the census variables, this index can be easily adapted to other contexts, such as a study of access to specialized health programs targeting specific groups.

Some limitations of this study may suggest avenues for future research. The E2SFCA model inherently assumes residential location as the origin of "journey to community pharmacies" and measures accessibility based on the distance between residential locations (i.e., population-weighted dissemination area centroids) to pharmacy locations. While acknowledging that individuals may visit pharmacies located far from home but closer to work or other opportunities like hospitals, it is reasonable to assume a preference for frequenting pharmacies in one's local neighbourhood, especially for older adults, families with young children, and low-income individuals with limited mobility and resources. A prominent strength of the E2SFCA model is to be able to consider the attractiveness of service providers, such as store size. However, due to data limitations, all community pharmacies are treated equal in the E2SFCA model, while in reality, pharmacies vary by store attributes (e.g., drug dispensing fees, floor area, selection of health-related and general merchandise, price level, marketing/loyalty program, service) and externalities (e.g., location in mall vs. street front, ease of parking, proximity to other neighbourhood amenities). Given the cultural diversity of GTA's population, pharmacies that have pharmacists who can speak non-official languages may possibly attract individuals who are willing to travel a longer distance to access same-language pharmacists. Future research can employ fieldwork to collect detailed information about pharmacies in order for the E2SFCA model to more accurately measure geographic accessibility by taking into consideration differences among pharmacies. The E2SFCA model used in this study considers travel distance by driving and the model parameters are set by theoretical travel zones. In future research, survey-based primary data would be helpful to understand the travel behaviour of different groups who are accessing and using pharmacy services, including mode of transportation (e.g., walking, public transit, or car). In this study, the vulnerability index was created using three select census variables. Future research could consider more census variables representing vulnerable populations, such as unemployment status, and compare the results of that research to those of this study.

This study provides important implications for addressing issues of low pharmacy access among vulnerable groups with high needs, including older adults whose population share in the GTA has increased from 14.4% in 2011 to a record high of 16.9% in 2016. The "aging in place" trend in Canada and the limited long-term care infrastructure also mean a greater dependence on community pharmacies among older adults living in private dwellings in community settings. As revealed in this study, most of the under-serviced areas are outside of the city core, located in inner suburban and outer suburban neighbourhoods. The low-density and car-dependent geography of these neighbourhoods may present significant challenges for older adults, low-income families, and families with young children (especially newcomers and older immigrant women) who are attempting to access community pharmacies. The role of community pharmacies in under-serviced neighbourhoods should be explored further, using interview-based qualitative methods to investigate individual barriers to and facilitators of pharmacy use, and the associated unmet health needs of vulnerable groups.

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