Accessibility to healthcare via public transport across Canada

Geneviève Boisjoly
School of Urban Planning, McGill University
genevieve.boisjoly@mail.mcgill.ca

Robbin Deboosere
School of Urban Planning, McGill University
robbin.deboosere@mail.mcgill.ca

Rania Wasfi
Centre de Recherche du CHUM, Université de Montréal
rania.wasfi@crchum.qc.ca

Heather Orpana
Centre for Surveillance and Applied Research, Public Health Agency of Canada
heather.orpana@canada.ca

Kevin Manaugh
Department of Geography, McGill University
kevin.manaugh@mcgill.ca

Ron Buliung
Department of Geography and Planning, University of Toronto
ron.buliung@utoronto.ca

Ahmed El-Geneidy
School of Urban Planning, McGill University
ahmed.elgeneidy@mcgill.ca

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ABSTRACT

The ability to access healthcare services has long been considered a ‘right’ by Canadian citizens, and is protected as such under the Canada Health Act. However, socio-spatial factors can limit access to healthcare services, especially for vulnerable populations. This paper aims to quantify the spatial accessibility to healthcare services by public transport across eight major Canadian metropolitan areas, and compare accessibility to healthcare across vulnerable population groups. Spatial accessibility to general medical and surgical hospitals was measured through a two-step floating catchment area method, taking into account both service-to-population ratios and travel time to these health services. Within cities, accessibility is equitably distributed: residents of vulnerable census tracts generally have greater access to health services by public transport, with the exception of Vancouver. To quantify vertical equity, an indicator was subsequently developed using the Spearman’s rank correlation coefficient between accessibility and vulnerability. Results show that larger metropolitan areas (Calgary, Toronto-Hamilton, and Vancouver) tend to underperform in terms of vertical equity and average accessibility. This research highlights the challenges associated with the suburbanization of poverty in large Canadian metropolitan regions and the need to provide efficient public transport services to reach hospitals located in the periphery. This study is of relevance to researchers, planners and policy-makers wishing to improve accessibility to healthcare, especially for vulnerable populations.

INTRODUCTION

The ability to access appropriate healthcare services has been at the centre of Canadian healthcare policy for decades. One of the five pillars of The Canada Health Act states that "persons must have reasonable and uniform access to insured health services, free of financial or other barriers. No one may be discriminated against on the basis of such factors as income, age, and health status." (*1*) There has, however, been extensive debate on how to interpret this notion of accessibility, both in government and academia (*2*). In academia, the interpretation of accessibility has generally fallen into two distinct categories: potential and realized access to healthcare (*2; 3*). Potential access is considered to be a function of the geographic distribution and supply of healthcare services, while realized access refers to actual utilization rates (*4*). Health Canada, on the other hand, specifies that accessibility can refer to both socio-economic access (related to medical charges and a patient's age or health status) and the physical availability of "medically necessary services" (*5*). Nevertheless, there seems to be a consensus that a form of geographical or spatial access to healthcare falls within the concept of accessibility as defined in the Canada Health Act, and can therefore be interpreted as a 'right'. Such debate on a 'right' to access healthcare services is not unique to the Canadian context and is present in both developed and developing regions around the world. Considering the existence of spatial factors that increase barriers to access health services, inadvertently disadvantaging already vulnerable populations, it is especially pertinent to develop a methodology to measure spatial accessibility to healthcare and examine it from an equity perspective across different regions.

In Canada's major cities, an aging population progressively relies on public transport to access healthcare facilities due to conditions resulting in the loss of driving ability that are more frequent at older ages that (*6*). At the same time, hospitals have recently begun to increase parking costs, thus making an ever-larger share of this senior population, and the population at large – especially low-income individuals – dependent on public transport. This paper aims to quantify the spatial accessibility to healthcare services (specifically general medical and surgical hospitals) by public transport across eight major Canadian metropolitan areas, and compare accessibility to healthcare across vulnerable populations. An overview of the eight areas that were examined in this study can be seen in Figure 1. Spatial accessibility to healthcare is measured using a two-step floating catchment area method (2SFCA), incorporating both the spatial relationship between supply (captured by the number of beds) and demand for services (population), and competition effects for scarce resources (*7*). Comparison across cities allows identifying some of the main challenges to be addressed to improve accessibility to healthcare in Canada, especially for vulnerable populations, and sheds light on the factors to take into account in the allocation of health and transport resources.

The rest of this paper is structured as follows. In section 2, relevant literature is presented, while in section 3 the data and methodology used to calculate spatial accessibility are discussed. Section 4 presents the results of the accessibility calculations, and provides a comparison between Canadian cities in terms of average accessibility and the distribution of accessibility across socio-economic groups. Section 5 then concludes this paper.

Figure 1 Overview of the 8 metropolitan areas included in the study

LITERATURE REVIEW

A vast body of literature has established links between access to health services and health outcomes. Increased distances to healthcare facilities, for example, are associated with lower rates of utilization of the healthcare system (*8; 9*), often exacerbating pre-existing inequities in health status (*10; 11*). However, despite the substantial importance of these links, two distinct areas of research have independently been preoccupied with measuring and understanding access to healthcare services.

Transport scholars and practitioners usually measure access to (health) services through accessibility, which is defined as the ease of reaching destinations (*12-15*). Accessibility, first defined as the potential of opportunities for interaction (*16*), is often operationalized through the number of opportunities that can be reached from a certain point in space within a specified time limit, e.g. the number of hospitals that can be reached within 30 minutes of travel time– what is known as cumulative accessibility (*17*). Recent research has also proposed the use of variable thresholds to measure the number of healthcare clinics reachable in a region (*18*). Gravity-based accessibility measures further expand on the cumulative metrics by discounting services by distance; the further a service is, the less it contributes to accessibility (*19; 20*).

Health researchers often opt for simpler metrics of accessibility such as the distance to the nearest service, service-to-population ratios, or service areas (*21; 22*). The average travel time from a point in space to all health providers in a certain region has also been used for this purpose (*3*). In contrast with the transport-oriented metrics, these measures have the advantage of being easier to calculate and communicate to a large variety of audiences.

The above-mentioned metrics are however incomplete and cannot fully capture all dimensions related to spatial access to health services. Cumulative and gravity-based accessibility measures, for example, do not take into account demand side considerations; they assume that services will be fully available to residents, regardless of their capacity - one service 2 km away from one person would be equal to one service at a distance of 2 km away from a million individuals (*23*). The distance to the nearest service and service area metrics exhibit the same issues. The service-to-population ratio, on the other hand, does consider demand, but gives no indication as to how far individuals would need to travel to reach a service and is often calculated via aggregated areal units that are too large to conclude meaningful results (*3; 24*).

In response to the shortcomings associated with these metrics, the two-step floating catchment area method (2SFCA) was developed by Joseph and Bantock (*25)* (although not named as such) and later Luo and Wang (*23)*, the scholars responsible for coining the term. This method combines both demand and supply side metrics, and can accurately control for travel impedance, capacity restrictions and competition for services (*21*). As the name suggests, the 2SFCA consists of two stages, where in the first step the service-to-population ratio is computed for each service, and then in the second step cumulative or gravity-based accessibility is calculated based on the service-to-population ratios (*7; 26; 27*). In essence, the 2SFCA sums the service-to-population ratios of services that can be reached from a specified point in space. As demonstrated by Luo and Wang (*23)*, this is equivalent to the 'competitive' measures of access that are commonly used in transport research to measure accessibility to job opportunities (*28*-*31*).

Two competing notions of equity exist in transport research: horizontal and vertical equity (*32*-*34*). A distribution is considered horizontally equitable if everyone has the same accessibility, regardless of his or her personal socio-economic characteristics. The allocation of resources is vertically equitable if those with the highest need also have access to the most resources, where need is usually measured through socio-economic status. Accessibility metrics have often been employed to measure the equity of the spatial distribution of opportunities (*35*-*37*). However, most health studies measuring access to healthcare facilities have paid little attention to how both spatial and non-spatial characteristics, such as socio-economic status, relate to access levels (*38*). Furthermore, while many scholars have used metrics such as the Gini coefficient or the Lorenz curve to measure horizontal equity (*33*), little research has been undertaken to quantify vertical equity. To our knowledge, only one study has undertaken this task, by calculating vertical equity through a spearman correlation coefficient, although the authors did not apply this to an accessibility metric (*39*). This is, therefore, the first study to develop a vertical equity measure to assess the distribution of accessibility levels across socio-economic groups. The study combines the accessibility measures developed with the 2SCFA with household income data to provide a deeper understanding of the socio-spatial patterns of accessibility to healthcare.

DATA AND METHODOLOGY

Two distinct data sources were used to compute accessibility levels. Information on general healthcare services was obtained through the Canadian Institute for Health Information (CIHI). More specifically, the number of beds staffed and in operation for hospital services in Canadian provinces in 2015-2016 was used (*40*). CIHI provides the total number of beds associated with each hospital, and the information was subsequently geocoded using a Google API using hospital names and addresses. It is important to note that these data were not available for the Province of Quebec. Accordingly, metropolitan regions in Quebec are excluded from the analysis. While former studies have measured accessibility to primary healthcare based on medical clinics or community pharmacies (*18; 22; 41*), our study specifically focuses on hospital services, which reflects access to emergency rooms, major outpatient clinics, and specialized care. This kind of healthcare service was selected for two reasons: the supply of this type of service is more consistent across provinces (no registration required to access most of these services, except specialized ones) and the geographic access to such services typically implies longer travel distances, which may require individuals to travel by car or by public transport. The number of beds is used in this study to better capture the supply at each hospital, as it reflects the size of the hospital and potentially the diversity of healthcare services available (assuming larger hospitals offer more services). Other detailed information such as number of doctors in an emergency care unit or at the hospital can also be used as proxies, yet such information was not available across all regions. The total number of beds available in all hospitals in each of the eight regions, as well as the bed-population ratio (number of beds per 1,000 inhabitants), are presented in Table 1.

Table 1 Information on population and hospital beds in the eight metropolitan region

Metropolitan region	Population	Number of beds	Population-bed ratio (number of beds/1000 inhabitants)
Calgary	1,392,609	2616	1.88
Edmonton	1,321,426	3301	2.50
Halifax	403,390	1199	2.97
Kitchener–Cambridge–Waterloo	523,894	804	1.53
London	494,069	1715	3.47
Toronto–Hamilton	7,055,433	14670	2.08
Vancouver	2,463,431	6967	2.83
Winnipeg	778,489	2623	3.37

Sources: CIHI, 2018 hospital inventory (*40*); Statistics Canada Census 2016 (*42*)

Public transport schedules across the eight metropolitan regions were downloaded in the *General Transit Feed Specification* (GTFS) format from their respective transport agencies. All schedules were obtained for May 2017 where available, or as close to this date as possible depending on the release date of the GTFS data from the different agencies. If multiple agencies served a single metropolitan area, the schedules from all agencies were obtained with overlapping schedule dates. Public transport schedules were digitized into a geographic information system through the *Add GTFS to a network dataset* add-on for ArcGIS. To calculate accessibility to healthcare services, a travel time matrix was generated, providing the travel time from every census tract (CT) to each other CT in the region. The travel times were obtained by calculating the fastest route between CT centroids within each metropolitan area at 10 AM on a regular Tuesday. The fastest route algorithm incorporated walking time from the CT centroid (origin) to the public transport station, waiting time, in-vehicle time (as determined by the transit schedule), any transfer time, and walking time from the last stop to the CT centroid (destination). The 10 AM leaving time was chosen to account for an off-peak public transport service level.

A two-step floating catchment area method was subsequently used to calculate spatial accessibility. First, a service-to-population ratio V_j was calculated for each hospital, taking into account the total population that can reach the service within 45 minutes by public transport:

$$V_j = \frac{S_j}{\sum_k P_k\, f(t_{kj})} \; and \; \mathrm{f}(t_{kj}) = \begin{cases} 1 \; if \; t_{kj} \leq 45 \; minutes \\ 0 \; if \; t_{kj} > 45 \; minutes \end{cases}$$

where j denotes a healthcare service, S_j represents the capacity of this service (number of beds), P_k is the population in census tract k and t_{kj} is the travel time between census tract k and healthcare service j. $P_k\, f(t_{kj})$ can therefore be interpreted as the population at location k that can reach the service within 45 minutes by transit. Second, accessibility for each census tract was computed by summing the service-to-population ratios for the services that can be reached from each census tract centroid within 45 minutes:

$$A_i = \sum_j V_j \, f(t_{ji}) \; and \; f(t_{ji}) = \begin{cases} 1 \; if \; t_{ji} \leq 45 \; minutes \\ 0 \; if \; t_{ji} > 45 \; minutes \end{cases}$$

where i denotes a census tract, V_j is the service-to-population ratio for service j, and t_{ji} is the travel time between j and i via public transport. The accessibility measure thus counts the number of beds available within 45 minutes, and adds the service-to-population ratio for each service. As specialized healthcare is typically provided at the metropolitan level, rather than the neighborhood level, the threshold was selected to reflect metropolitan accessibility. Accordingly, a 45-minute threshold was selected, as is commonly used in transport planning to measure regional accessibility (*14*).

To assess the socio-spatial distribution of accessibility levels, a vulnerability index was computed representing the vulnerability of a census tract based on the characteristics of its population. Four variables were used to measure vulnerability, based on Foth, Manaugh and El-Geneidy (*32)*: (i) median household income (I), (ii) unemployment rate (U), (iii) the percentage of the population that has immigrated within the last 5 years (IM), and (iv) the percentage of households that spend more than 30% of their total income on housing rent (R). All variables were obtained from the 2016 Census of Canada and were then standardized through z-scores. The final vulnerability index is given by:

$$Vulnerability = -I + U + IM + R$$

Vertical equity was then calculated for each metropolitan region to assess the distribution of accessibility to health services (number of beds in a hospital that are reachable within 45 minutes of travel time weighted by the population that can reach the service within 45 minutes) based on the vulnerability indicator. The correlation between the vulnerability index and accessibility levels was generated through a Spearman's rank correlation index, as done in previous research (*39*). This approach assigns an accessibility rank and a vulnerability rank to each census tract and assesses whether census tracts ranking high in terms of accessibility also rank high in terms of vulnerability index. A coefficient of 1 would mean that the accessibility ranking is exactly the same as the vulnerability ranking, where the census tract with the highest accessibility also has the highest vulnerability index, and the census tract with the lowest accessibility has the lowest vulnerability index. Accordingly, the Spearman rank correlation coefficient indicates whether census tracts with high vulnerability (and accordingly high potential needs in terms of transport and health) also have the highest accessibility, which is desirable from a vertical equity perspective.

RESULTS

A comparison between average accessibility to healthcare for all residents in a metropolitan area and the average accessibility experienced by the residents in the 20% most vulnerable census tracts is shown in Figure 2. Looking first at the average accessibility to healthcare for all residents, we see that Halifax, London and Winnipeg have the highest average accessibility to healthcare for all residents, likely due to the large number of beds relative to the population (respectively 2.97, 3.47 and 3.37 beds per 1,000 inhabitants). In contrast, Kitchener–Cambridge–Waterloo and Calgary have the lowest bed to population ratios (1.53 and 1.88 respectively), which results in the lowest levels of accessibility among Canadian cities. Interestingly, Vancouver exhibits a high ratio (2.83), similar to Halifax, but is characterized by a low average accessibility to healthcare. This suggests that, while the quantity of supply is an important determinant of accessibility, other factors come into play when examining accessibility to healthcare services, namely the spatial distribution of hospitals and the performance of the public transport network, two themes explored in the next section.

In terms of equity, vulnerable census tracts are characterized by higher accessibility to health services than the average of the region. In Halifax, this difference is most profound: residents in vulnerable census tracts can access 88% more services than average (accessibility values of 6.87 and 3.64, respectively). Those residents also experience the highest accessibility value across all regions, although the highest average accessibility (including all census tracts) is found in London. In contrast, Vancouver has the lowest accessibility levels of all metropolitan areas with respect to the 20% most vulnerable census tracts, almost 4 times less than the average for the 20% vulnerable census tracts in Halifax (accessibility values of 1.74 and 6.87, respectively). Most notably, in Vancouver, vulnerable census tracts exhibit a lower accessibility to healthcare services compared to the average of the metropolitan region. This reflects an inequitable distribution of accessibility from a vertical equity standpoint, as vulnerable populations, which are more likely to depend on public transport to access healthcare services, experience lower accessibility than average.

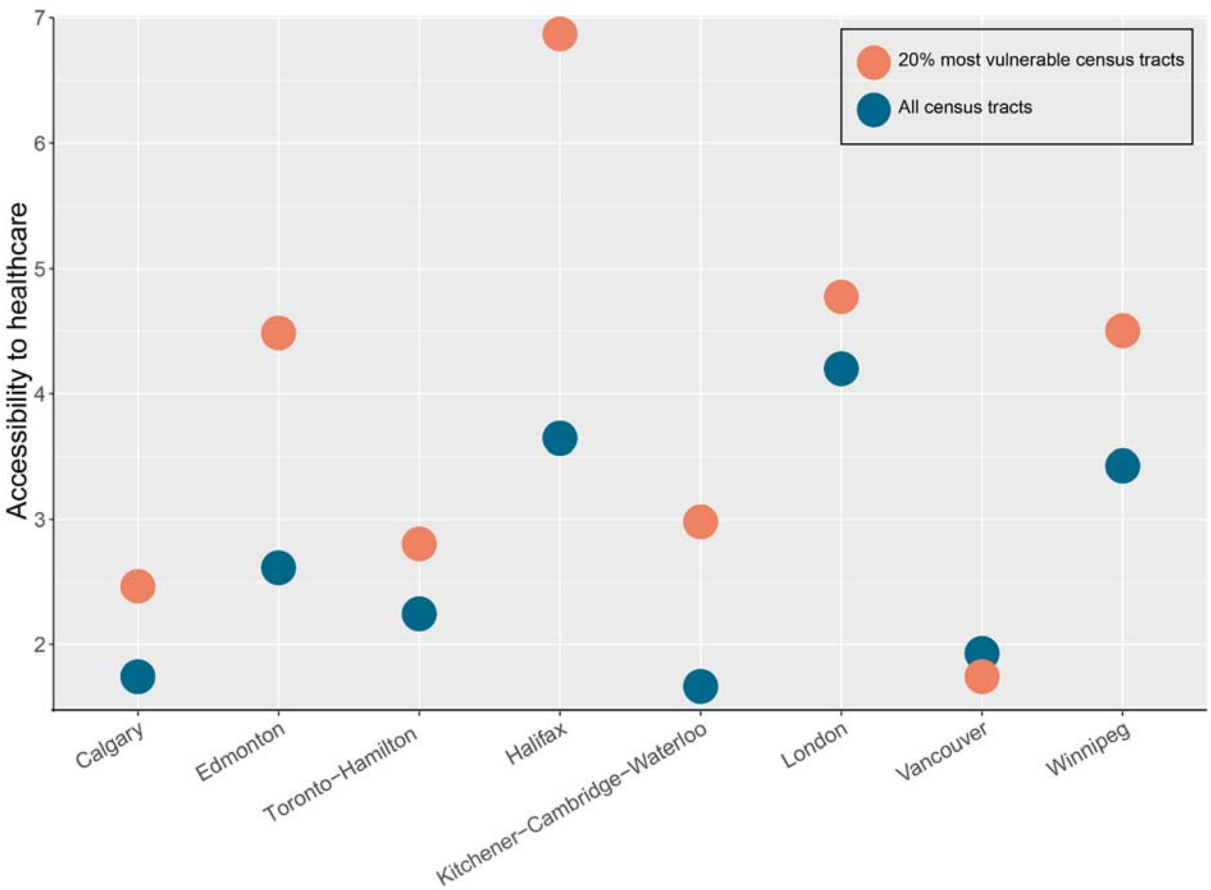

Figure 2 Comparison of accessibility levels across the eight metropolitan areas

To further explore the socio-spatial distribution of accessibility across metropolitan regions, a vertical equity indicator was calculated for each metropolitan region, using the Spearman's rank correlation index. Figure 3 compares the eight metropolitan areas based on average accessibility to healthcare (x-axis) and vertical equity of accessibility to healthcare (y-axis). The size of the circles corresponds to the size of the metropolitan population. A city at the top right corner would represent the ideal situation: a region with high levels of access to hospital beds overall, and where this access is equitably distributed across different socio-economic groups, i.e., where the individuals residing in vulnerable census tracts typically experience higher accessibility. Not surprisingly, Vancouver is amongst the metropolitan regions with the lowest vertical equity indicator, given that the accessibility of vulnerable census tracts in Vancouver is lower than the average of the region. Conversely, Halifax is characterized by a high vertical equity indicator as vulnerable census tracts have a much higher accessibility than the average of the region. More generally, metropolitan regions where the vulnerable census tracts exhibit the highest levels of accessibility across Canada (Edmonton, Winnipeg, Halifax and London) perform well on both indicators. Conversely, in regions with low average accessibility and low vertical equity (Calgary, Toronto–Hamilton and Vancouver), vulnerable census tracts exhibit the lowest levels of accessibility to healthcare across Canada. This highlights the difficulty to serve vulnerable census tracts when the average accessibility to healthcare is already low.

Also, as a general trend, it appears that larger metropolitan regions tend to perform worse in terms of vertical equity, with Calgary, Toronto–Hamilton, and Vancouver having the lowest vertical equity indicators. One possible reason explaining this is the suburbanization of poverty, combined with the concentration of healthcare services in the center. In contrast, smaller cities such as Halifax, London and Kitchener–Cambridge–Waterloo and Winnipeg, are characterized by a high level of vertical equity. This is likely explained by the fact that most of the vulnerable census tracts in these cities are located in or near the downtown area, where several hospitals are located. Vulnerable census tracts in these cities therefore have a high accessibility to healthcare relative to the rest of the region, resulting in a high vertical equity indicator.

Overall, the results demonstrate a higher performance among smaller metropolitan regions (with the exception of Kitchener–Cambridge–Waterloo explained by the low bed-population ratio) both in terms of vertical equity and average accessibility to healthcare services. Conversely, larger metropolitan areas exhibit low vertical equity and low average accessibility, which results in low accessibility in the vulnerable census tracts. This is potentially due to low bed-population ratio (in Calgary and Toronto–Hamilton) but also to the difficulty to serve a population that is spatially dispersed. Accordingly, the results suggest that more efforts are needed in larger metropolitan regions to increase accessibility to healthcare, especially for vulnerable census tracts.

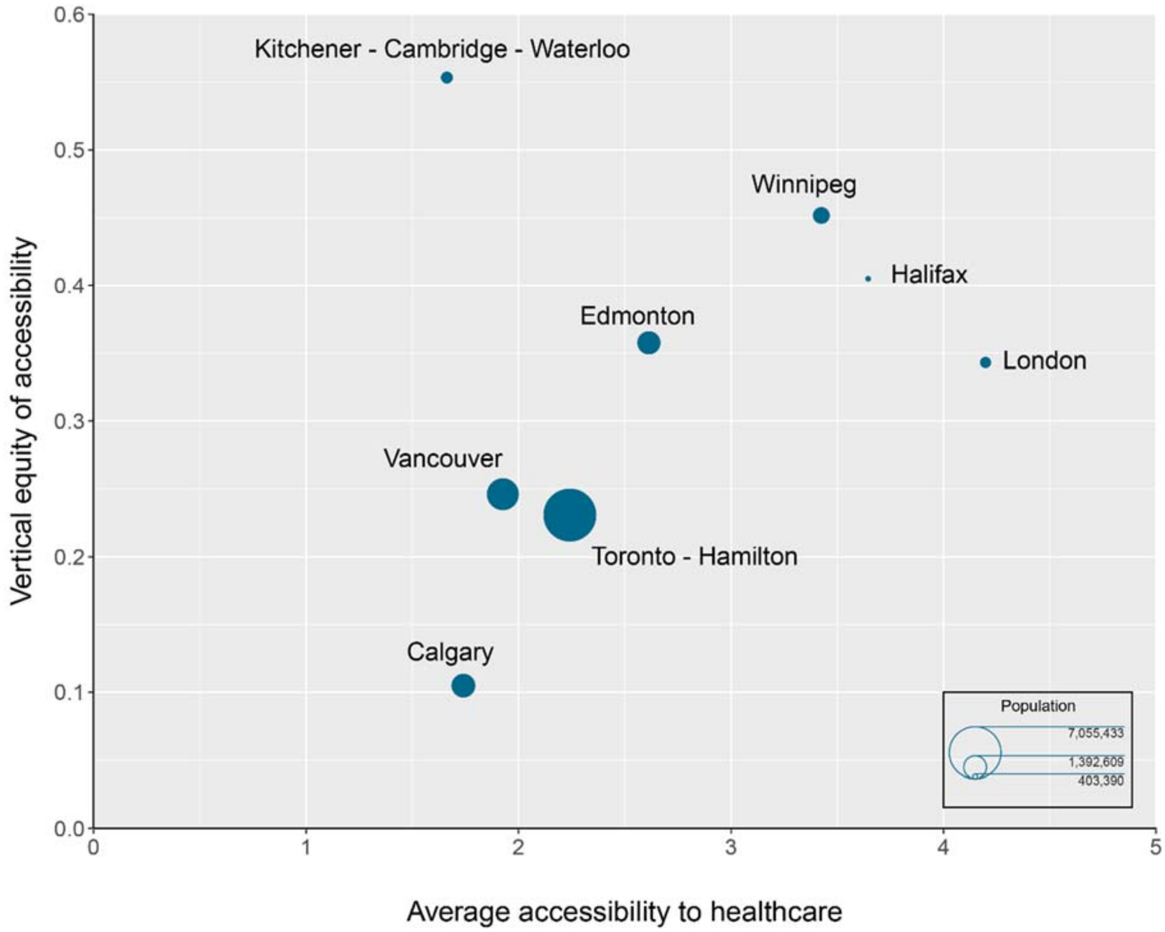

Figure 3 Accessibility and vertical equity across the eight metropolitan areas

DISCUSSION

To better understand how metropolitan regions can support a greater and more equitable access to healthcare services, this section explores the key land use and transport factors that lead to low accessibility to healthcare in some of the regions, especially for vulnerable populations, as observed earlier in the results. Figure 4 maps the accessibility to healthcare in Vancouver and Edmonton, with the 20% most vulnerable census tracts identified with a black outline. These two metropolitan regions were selected as they demonstrate the contrasts between large and small metropolitan regions, and highlight several of the issues that metropolitan regions are facing in terms of accessibility to healthcare.

With respect to the average accessibility to healthcare, we see that, in both cases, the fringes of the metropolitan region experience low levels of accessibility, given the lack of hospitals and of public transport services. Most notably, we see important discrepancies in accessibility exist between the center and the periphery in Winnipeg: whereas several central census tracts have an accessibility level above 6, all census tract in the periphery are characterized by a null accessibility, largely due to the limited public transport service in peripheral areas. The detailed assessment of accessibility reveals an uneven distribution across the region, although the average accessibility of the region is high. This is also the case in smaller metropolitan regions such as London and Halifax. It is important to note that, while most vulnerable census tracts are located in central areas in these regions, resulting in a high vertical equity indicator, there are certainly vulnerable populations residing in the periphery. Smaller metropolitan regions should thus concentrate on these populations and explore interventions that could support a high level of accessibility by public transport to hospitals for these populations groups.

Turning now to the Vancouver metropolitan region, where average accessibility is low, we see that very few census tracts have a high level of accessibility (above 6). Furthermore, most hospitals located in the periphery of the region are only accessible to a limited number of census tracts in their surroundings, which limits the level of accessibility by public transport experienced by residents outside the central areas and not in the immediate surroundings of these hospitals. Improving public transport services to these hospitals could lead to an increased accessibility in the periphery. In other words, the decentralization of services in Vancouver should be accompanied by improved public transport services if one wishes to support high levels of accessibility by public transport to healthcare in the suburban areas.

In terms of vertical equity, we see that most of the vulnerable census tracts are located away from the city center, where there is a high concentration of hospitals. As a result, vulnerable census tracts experience lower levels of accessibility. In order to support high accessibility in vulnerable census tracts that are not located in the center, it is essential to support the decentralization of healthcare services, considering where vulnerable census tracts are located, and to improve the provision of public transport services to these hospitals. For example, there is a cluster of vulnerable census tracts in the south-east of the region with an accessibility between 0 and 2. Accessibility from these census tracts could be improved by providing more services in that region (opening new hospitals or adding more beds within the existing ones), or by improving accessibility by public transport to the surrounding hospitals, especially those that are currently characterized by a low competition (to the South for example). This would also contribute to improving the level of accessibility by public transport to healthcare services in the region.

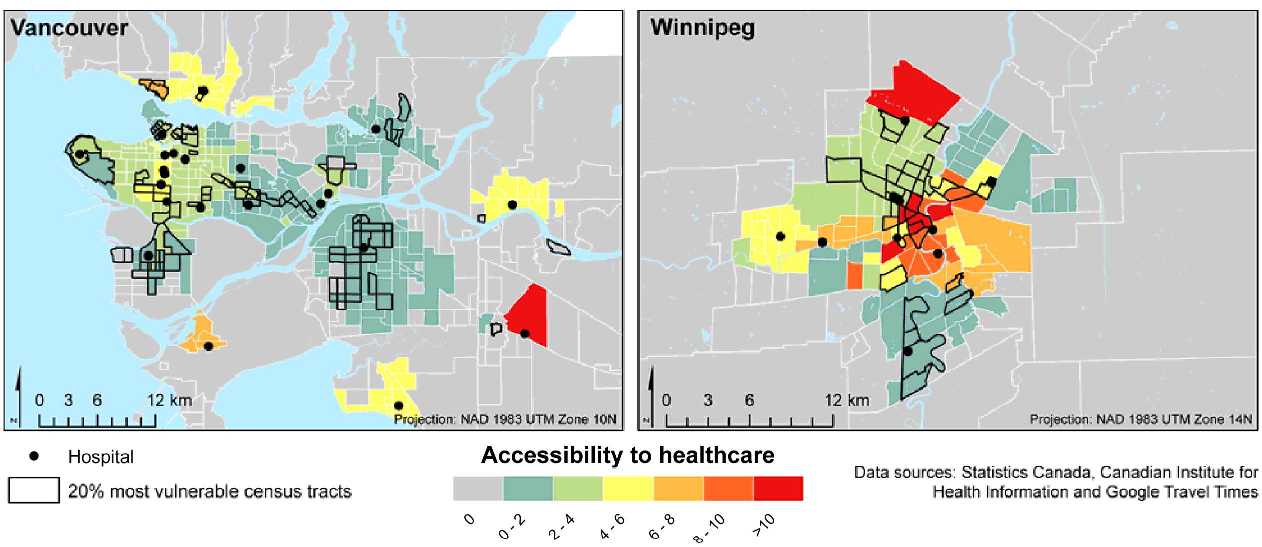

Figure 4 Accessibility to healthcare in Vancouver and Winnipeg, Canada

It is important to note that similar patterns, although not as pronounced, are present in Calgary and in Toronto–Hamilton. More generally, research conducted in large Canadian metropolitan regions has shown that a growing proportion of low-income households locate in the inner suburbs of these regions (*43; 44*). The suburbanization of poverty, in addition to the lack of efficient public transport services in the suburbs, represents a significant challenge in providing adequate access to healthcare services in Canada. The suburbanization of poverty is not unique to Canadian cities, but is present in medium- and high-income countries around the world (*45-48*). The concentration of low-income households in the suburbs and urban fringes is also a significant problem in several cities of the Global South, namely in Latin America, where such spatial segregation has been around for many decades (*49; 50*). This study demonstrates that the development of land use and public transport interventions in suburban areas would substantially contribute to higher levels of accessibility to healthcare overall, and more importantly for vulnerable populations. Furthermore, the methods applied in this paper can be applied in other areas around the world facing similar issues to help setting priority interventions to increase accessibility to healthcare services.

CONCLUSION

This study has examined spatial accessibility to general medical and surgical hospitals across eight metropolitan regions in Canada accounting for both the travel times by public transport and the service-to-population ratio, where the number of beds is used as proxy for the level of service. Results find that in all cities except for Vancouver, the socio-spatial distribution of accessibility to health services is vertically equitable: residents in the 20% most vulnerable neighbourhoods live in areas with higher accessibility than average for their cities. The groups with the highest needs thus tend to also experience the highest accessibility. This advantage is, however, less pronounced (or simply absent) in larger metropolitan regions (Calgary, Toronto-Hamilton and Vancouver), which also exhibit relatively low average accessibility overall. As a result, vulnerable census tracts in these large metropolitan regions exhibit the lowest levels of accessibility to healthcare services by public transport across Canada. This is largely explained by the lack of accessibility by public transport to the hospitals located in the peripheries, and the high proportion of vulnerable households in the inner suburbs of the regions, resulting from the suburbanization of poverty that many large cities around the world have been experiencing. Improving accessibility by public transport to healthcare services in the suburbs would contribute to improving the well-being of individuals, especially for vulnerable groups.

The study has demonstrated how different indicators can be used to assess access to healthcare in different regions. In metropolitan regions with low levels of accessibility and also low vertical equity, vulnerable census tracts typically experience lower levels of accessibility to healthcare. It is, however, necessary to go beyond these indicators, as demonstrated in the previous section, to better understand the socio-spatial distribution of accessibility to healthcare services and to provide context-specific recommendations. For example, in Vancouver, several peripheral hospitals have low competition and improving public transport to these hospitals would significantly help in increasing vertical equity and average accessibility. In the case of Winnipeg, the specific analysis of the metropolitan region depicts high regional inequities between the centre and the periphery, although the region as a whole has a high average accessibility. Improving public transport to reach hospitals from the periphery would contribute to a more even spatial distribution. Overall, while similar trends can be observed in different metropolitan regions, context-specific interventions are required to improve access to healthcare. In line with this, further studies are required to assess how access to healthcare is considered in public transport planning and health policies in the different regions.

It is important to acknowledge the limitations of this study. First, accessibility to hospitals was measured at the census tract level, using the centroid of the census tracts as the point of reference for calculating travel times. This does not reflect the exact location of healthcare services, especially when considering large census tracts (mostly located in the periphery of the region), and, as a result, travel times to the hospitals might by under- or over-estimated. In most cases, the impact on the calculated accessibility is minimal, as there is no or little difference in the travel time. In a few cases where the hospital is situated at the boundary of a large census tract, a more important difference can be found between the travel time calculated using the centroids of the census tract and the travel time that would result from using the exact location of the hospital. As large census tracts are typically located in the periphery where public transport services are limited, the impacts (overestimation or underestimation) on accessibility, if any, are limited to the few census tracts surrounding the hospital, the others being more than 45 minutes away no matter how travel time is calculated. The results presented in this study are nonetheless representative of the general patterns of accessibility at the metropolitan level. Further studies could be conducted using a finer spatial resolution, to get a more detailed accessibility assessment for the peripheral areas. A second limitation is that we used travel time at 10 AM to account for off-peak public transport service level, although individuals may need to visit the hospital at any time of the day. In major public transport agencies, off-peak services are generally slower due to the reduced number of vehicles operating and increase in waiting and transfer times, while in-vehicle time is generally lower when compared to peak services. We expect that accessibility to healthcare services during the peak periods will be higher due to increase in the levels of services, yet we do not expect major variations in the spatial distribution of accessibility. It is also important to point out that while this study focused on accessibility to general medical and surgical hospitals - which represents a key component of the universal healthcare system in Canada - further studies could look more specifically at primary care. Yet, since the primary care systems function differently from one province to another, province-specific analyses should be conducted to take into account these differences. Further studies could also build on the present study to evaluate the impacts of differential levels of accessibility to specialized care on vulnerable individuals. This would contribute to a better understanding of what the accessibility metric presented in this study reflect in terms of actual healthcare services received.

Overall, this study provides a comprehensive view of accessibility to general medical and surgical hospitals across eight Canadian cities and demonstrates the growing challenges that Canadian metropolitan regions, and potentially many other cities around the world, are facing in terms of equity and accessibility to healthcare services. Urban policy-makers and public health professionals could build on this study to assess the levels of access to healthcare across various socio-economic groups in their cities, and to subsequently implement policies aimed at improving overall accessibility and accessibility for vulnerable populations to healthcare services by public transport.

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AUTHORS CONTRIBUTIONS

The authors confirm contribution to the paper as follows: study conception and design: Boisjoly, Deboosere, Wasfi, Orpana, Manaugh, Buliung, & El-Geneidy; data collection: Deboosere, Wasfi, Orpana, & El-Geneidy; analysis and interpretation of results: Boisjoly, Deboosere, Wasfi & El-Geneidy; draft manuscript preparation Boisjoly, Deboosere, Wasfi, Orpana, Manaugh, Buliung, & El-Geneidy. All authors reviewed the results and approved the final version of the manuscript.

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