GEOGRAPHIC ACCESS TO FAMILY PHYSICIANS IN URBAN AREAS ACROSS CANADA

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By

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Keywords: spatial accessibility, family physicians, health geography, urban geography, spatial statistics, physicians to population ratio

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ABSTRACT

Primary health care (PHC) is a term used to refer to the parts of the health system that people interact with most of the time when health care is needed. It is considered the first point of contact for health services in Canada. Access to PHC services is an important issue regarding health care delivery in Canada today. There is a need to advance current understanding of access to PHC providers at local scales such as neighbourhoods. The primary objective of this study is to examine the variation in geographic (spatial) accessibility to permanently located primary care services in the Canadian urban environment. Furthermore, the analysis of spatial patterns of accessibility, both visually and statistically using GIS, is to provide a better understanding of among and between neighbourhood variations.

This research took place in the 14 urban areas across Canada: Victoria and Vancouver, British Columbia; Calgary and Edmonton, Alberta; Saskatoon, Saskatchewan; Winnipeg, Manitoba; Hamilton, and Toronto, Ontario; Montréal and Québec, Quebec; Halifax, Nova Scotia; St. John's, Newfoundland; Saint John, New Brunswick; and Ottawa–Gatineau, Ontario and Quebec. A GIS based method, the Three-Step Floating Catchment Area (3SFCA), was applied to determine the spatial accessibility to PHC services (accessibility score). First, for increasing geocoding match rates with reduced positional uncertainty, an integrated geocoding technique was developed after an empirical comparison of the geocoding results based on manually built and online geocoding services and subsequently applied to generate geographic coordinates of PHC practices which are an essential element for measuring potential access to health care.

Next, the results of the Three-Step Floating Catchment Area (3SFCA) method was compared with simpler approachs to calculate the City level physician-to-population ratios and this research highlights the benefit of using the 3SFCA method over simpler approaches in urban areas by providing similar or comparable results of City level physician-to-population ratios with the advantage of intra-urban measurements. Further, the results point out that considerable spatial variation in geographical accessibility to PHC services exists within and across Canadian urban areas and indicate the existence of clusters of poorly served neighbourhoods in all urban areas.

In order to investigate the low accessibility scores in relation to population health care needs, spatial statistical modeling techniques were applied that revealed variations in geographical accessibility to PHC services by comparing the accessibility scores to different socio-demographic characteristics across Canadian urban settings. In order to analyse how these relationships between accessibility and predictors vary at a local scale within an urban area, a local spatial regression technique (i.e., geographically weighted regression or GWR) was applied in two urban areas. The results of GWR modelling demonstrates intra-urban variations in the relationships between socio-demographic variables and the geographic accessibility to PHC services. In addition, the influences of "unit of analysis" on accessibility score were analyzed using spatial statistical modeling that emphasize the use of units of analysis that are pertinent to policy and planning purposes such as city defined neighbourhoods.

Overall, this research shows the importance of measuring geographic accessibility of PHC services at local levels for decision makers, planners, researchers, and policy makers in the field of public health and health geography. This dissertation will advance current understanding of access to primary care in Canadian urban settings from the perspective of the neighbourhood.

ACKNOWLEDGMENTS

Dedication

This dissertation is dedicated to the memory of my parents (Muhammad Ikram Shah and Tahira Ikram) and brother Tahir Ikram Shah. This work is also dedicated to my family members and teachers.

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LIST OF ABBREVIATIONS

The following table describes the significance of various abbreviations and acronyms used throughout the thesis. The page on which each one is defined or first used is also given.

CHAPTER 1: GENERAL INTRODUCTION

Chapter 1 provides a brief overview of the access to primary health care in the context of

Canadian health care system along with the rationale for the study, introduces the research

objectives, and a brief description of the research design.

CHAPTER 1
GENERAL INTRODUCTION

Background

In Canada, health care accessibility is a pressing research and policy issue that is relatively

unstudied in the context of urban settings, particularly with a focus on neighbouhoods and other

small urban sub-units. One objective of the Canada Health Act (CHA or the Act) is "to protect,

promote and restore the physical and mental well-being of residents of Canada and to facilitate

reasonable access to health services without financial or other barriers." It aims for a national

health care system that is capable of providing universal, portable, comprehensive,

administrated, and accessible health services to all Canadians. Primary health care (PHC) is a

term used to refer to the part of health system that people interact with most when they need

health care and is the first-point-of-contact between an individual and primary care; it includes

health care practitioners such as a family physicians or general medical practitioners, nurse

practitioners, or pharmacists in Canada (Crooks & Andrews, 2009; Health Canada, 2006). PHC

is a set of health care services that generally focus on diagnosis and treatment, illness prevention,

health promotion, as well as referrals to specialists (Health Canada, 2006).

The term family physician (or general practitioner) refers to a physician who has family

medicine training. According to Rakel (2011, p. 5), "family physicians possess distinct attitudes,

skills, and knowledge that qualify them to provide continuing and comprehensive medical care,

health maintenance, and preventive services to each member of a family regardless of gender,

age, or type of problem (i.e., biologic, behavioral, or social)." The Canadian Institute for Health

Information (CIHI) report indicates that there were 36, 769 family physicians or general practitioners (i.e., 50.7% of the physician workforce in Canada; ranging from 55.6% in Saskatchewan to 49.0% in Ontario) in Canada and a majority of them were working in urban areas (i.e., 75.4% of family physicians in Canada) in 2011 (Canadian Institute for Health Information, 2012). The location of physicians plays a central role in health care delivery (Joseph & Phillips, 1984). How physicians choose their practice sites can be influenced by environmental and or behavioral factors (Joseph & Phillips, 1984). Environmental factors are related to area characteristics – current patterns of physician distribution, locations where businesses are allowed, potential patients, etc., whereas behavioral factors are related to the physician's more personal decision regarding choice of practice location (Joseph & Phillips, 1984; Kazanjian & Pagliccia, 1996). Joseph & Phillips (1984) focused on the individual preferences in the context of locational choice of physicians identifying three important components of attitude formation: personal, professional, and class or lifestyle. In a survey of practicing physicians in the province of British Columbia, Kazanjian & Pagliccia, (1996) found that physicians, regardless of urban and rural location, ranked spousal influence to be the most important in the choice (decision) of the practice location.

Access to PHC services, one of the five fundamental principles of The Act, is an important issue in Canada. In the absence of a clear elucidation of accessibility principle, the following quote, "reasonable access to medically necessary hospital and physician services," could be interpreted in many ways to comply with the Act in the interest of Citizens. These interpretations could be based on some compositional and or contextual characteristics of predisposing, enabling, and need factors (Aday & Andersen, 1974; Andersen, McCutcheon, Aday, Chiu, & Bell, 1983). Generally, research on access to health care is divided into two

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domains: the first domain is related to the study of the distribution or availability of health care services in association with population needs, or simply, potential access to health care services. The second domain deals with the actual utilization of health services, also referred to as realized access. In health geography, potential access is further explored based on geographic parameters such as location, spatial structure, or distance-decay as well as non-geographic parameters including socioeconomic status, income, age, or gender (Khan, 1992; Luo & Wang, 2003).

In health geography, information on provision of health care resources (i.e., supply) and population demand for health care are important for measuring spatial (geographic) access to health care. Generally, geographic accessibility to health care resources measures can be categorized into two different approaches (Joseph & Phillips, 1984). The first approach involves measuring regional availability with the assumption that regional boundaries are impermeable (suitable for large regions, for example, census divisions (Pong & Pitblado, 2005), health areas (Olatunde, 2007; Thommasen & Thommasen, 2001), and utilization-based service areas (Shipman, Lan, Chang, & Goodman, 2010)). The second approach uses spatial interaction processes (e.g., distance decay) in the manipulation of supply and demand data at local scales (Cromley & McLafferty, 2012; Guagliardo, 2004; Joseph & Phillips, 1984, pp. 310-325; Luo & Wang, 2003; Schuurman, Berube, & Crooks, 2010; Wang, 2012) which normally based on the following techniques: Gravity models and kernel density estimations. In human geography, modified gravity models such as Two Step Floating Catchment Area (2SFCA) (Luo, 2004; Luo & Wang, 2003; Radke & Mu, 2000; Wang & Luo, 2005) method and associated enhanced versions of 2SFCA method (Bell, Wilson, Bissonette, & Shah, 2013; Bissonnette, Wilson, Bell, & Shah, 2012; Cromley & McLafferty, 2012; Delamater, 2013; Luo & Whippo, 2012; Ngui & Apparicio, 2011; Wan, Zou, & Sternberg, 2012).

Urban environments can influence many aspects of health and well-being and access to health care is one of them (Canadian Institute for Health, 2006; McLafferty, Wang, Luo, & Butler, 2011). In Canada, most of the research on access to health care is focused on national and provincial levels (Allin, Grignon, & Le Grand, 2010). One of the most important aspects of a spatial and quantitative research project is the unit of analysis. The size and shape of the area investigated (county units, postal codes, census tracts) may produce different results depending on the chosen political unit of study (Nykiforuk & Flaman, 2008). For quantitative analysis, census boundaries (units) have been used frequently to delineate neighbourhood boundaries (Stafford, Duke-Williams, & Shelton, 2008). In the UK, neighbourhood boundaries typically coincide with enumeration districts and electoral ward boundaries; in the US and Canada are often coincidental with boundaries of census units, such as census blocks (US) or tracts (US and Canada), but not always and not perfectly (Flowerdew, Manley, & Sabel, 2008). In combination local knowledge, natural boundaries (e.g. rivers and contours) and the man-made landscape (e.g. major roads) can be used to define neighbourhoods and are often, more meaningful for local residents (Ross, Tremblay, & Graham, 2004). In addition, some neighbourhoods may be defined based on homogeneity in population or housing characteristics (Flowerdew, et al., 2008). In direct comparison between a 'natural' neighbourhood approach and an approach which uses pre-defined census geostatistical units, the natural neighbourhoods approach responds to calls in the literature to produce more ecologically meaningful units of analysis (Ross, et al., 2004; Stafford, et al., 2008) for the study of area effects on health status in Montreal, Canada (Ross, et al., 2004), while the (Stafford, et al., 2008) found the estimates of the extent of variation in health across neighbourhoods – neighbourhood inequalities in health – very similar irrespective of the way in which the neighbourhood boundaries were defined. The determination of neighbourhoods for

empirical purposes is problematic, and any definition may be challenged (Ross, et al., 2004) while the choice of unit should logically be reflective of the purposes of the research at hand (Diez-Roux, 2001). The delineation of neighbourhoods is less challenging in situations when municipalities recognize them for planning purposes and these boundaries have meaning for local residents. In such cases, neighbourhood boundaries are locally defined and based on a variety of locally relevant factors.

Need for Research in Geographic Access to Family Physicians

Recently, researchers have shown an increasing interest in potential access to PHC services to identify under-served areas (or under-served populations) (Bell, et al., 2013; Bell, Wilson, Shah, Gersher, & Elliott, 2012; Guagliardo, Ronzio, Cheung, Chacko, & Joseph, 2004; Ngui & Apparicio, 2011; Roeger, Reed, & Smith, 2010). There are growing concerns in Canada that the health system is not as responsive as it could be for certain areas (and for certain populations) (Health Canada, 2001), particularly those areas where inequities in access to PHC services exist. There is a need to examine the distribution of PHC resources and potential access to PHC services at a local scale in urban environment. Penchansky & Thomas, (1981) indicated that the distribution of health care resources in relationship with population health care demand varies across space to meet the needs of residents matters. In Canada, among many initiatives for the health of people, public health policies are focused on providing adequate health care as close to one's place of living as possible (Government of Ontario, 2012). However, there has been little to no change in the proportion of the population age 12 and over with a regular medical doctor

nationally (i.e., 86% in 2005[1] and 85.1% in 2012[2]) (Minister of Health, 2011). In comparison, the number of physicians over the five years period from 2007 to 2011 increased at a much higher rate (almost three times) than the population (i.e., 13.9% as compared to 4.7% respectively). Not having a doctor could be the result of a mismatch between population needs and availability of health care resources at local scales, either physicians not taking new patients, retirement of physicians, or no doctors in their area (Nabalamba & Wayne, 2007; Statcan, 2014). Comparisons of geographic accessibility to PHC services across Canadian urban settings is helpful, as it improves our understanding of population health needs at a variety of scales and across Canada.

Recent evidence suggests that those who reside in urban settings (or sprawling urban areas) face similar challenges to those living in rural communities in terms of finding family physicians (Guagliardo, et al., 2004; McLafferty, et al., 2011; Mobley, Root, Anselin, Lozano-Gracia, & Koschinsky, 2006; Sibley & Weiner, 2011), but the distribution of PHC resources in urban areas needs additional attention and a different perspective to ensure "comprehensive care for patients and their families within the community, with a focus on prevention, management of chronic disease, and coordination of care" (Scott & Chami, 2013). However, too little attention has been paid to the geographical accessibility to health care resources in urban settings. Mostly this is because of apparent health care supply/availability figures in large urban settings, it is assumed there are no such underserviced or poorly served areas in urban settings. What is not yet clear is the potential geographical accessibility to family physicians (i.e., PHC providers) across Canadian urban areas and its distribution within the urban fabric to determine the underserviced or poorly served neighbourhoods. Among many challenges to health care delivery in urban areas is the relationship between the arrangement of family physicians clinics (i.e., PHC facilities) and

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[1] http://www4.hrsdc.gc.ca/.3ndic.1t.4r@-eng.jsp?iid=9#M_1
[2] http://www.statcan.gc.ca/tables-tableaux/sum-som/l01/cst01/health75b-eng.htm

the populations they are meant to serve. So far, however, there is a general lack of research about intra-urban distribution of family physicians (i.e., PHC services) particularly in relation with population health care needs. Therefore, this study offers some important insights into intra-urban patterns of geographical accessibility to family physicians and the relationship between geographical accessibility to family physicians and the socio-demographic characteristics of nearby populations across Canadian urban settings.

There is a consensus among human geographers that analytical results can be influenced by the number of areal units used (i.e., scale effect) and zonation effect (i.e., due to the choice of boundaries or level of aggregation) (Flowerdew, et al., 2008; Fotheringham & Wong, 1991; Haynes, Daras, Reading, & Jones, 2007; Hayward, 2009; Openshaw, 1983; Parenteau & Sawada, 2011; Séguin, Apparicio, & Riva, 2011). Many datasets are collected at the micro-scale (for example, the household) but are released and shared only after being aggregated to at the smallest possible geographic scale (such as Dissemination Areas "DAs" in Canada, Statistical Area Level 1 "SA1"[3] in Australia, Census Blocks "CB" or Block Groups "BG" in USA[4] and other larger units). In the process of data aggregation at higher (or larger) spatial scales (e.g. census tracts, neighbourhoods, census sub-divisions, census districts, etc.), variability in the dataset and statistical estimation can be different. This dissertation seeks to investigate whether the associations between geographic accessibility to PHC services and socio-demographic characteristics particularly in urban settings vary depending on the use of different areal units for analysis.

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[3] http://www.abs.gov.au/ausstats/abs@.nsf/0/7CAFD05E79EB6F81CA257801000C64CD
[4] http://www.census.gov/geo/reference/garm.html

Research Objectives

The overall goal of this study is to advance current understanding of access to PHC services and PHC service providers at a local (neighbourhood) scale across Canadian urban settings. The specific purpose is to examine access to and of PHC services in the urban areas across Canada. To accomplish this, the research is focused on measuring spatial accessibility to and of PHC services in a Geographical Information Systems (GIS) environment in the selected urban areas. The research is conducted in 14 selected urban areas (those subsets of each Census Metropolitan Areas (CMA) for which locally relevant neighbourhoods exists) Victoria, Vancouver, Calgary, Edmonton, Saskatoon, Winnipeg, Hamilton, Toronto, Montréal, Québec City, Halifax, St. John's, Saint John, and Ottawa–Gatineau to accomplish the following objectives:

- To measure the spatial accessibility to and of primary health care services in the selected 14 urban areas across Canada

- To identify under-served population at neighborhoods/local levels in the selected 14 urban areas.

- To analyze the patterns of spatial accessibility to primary health care between the neighbourhoods and among the urban areas using GIS and spatial statistical tools.

Figure 1-1. Locator map

Research Design

Research plan

This research is conducted in two steps (see Figure 1-2). In the first step, information about

primary health care providers is gathered from publicly available and routinely updated sources

(i.e. provincial colleges of physicians and surgeons), and converted into a proper digital format

which is used for mapping and analysis purposes. After cleaning and verification, data are

mapped using a geocoding process (applying a set of geographic coordinates to street addresses)

to measure spatial accessibility. The Three-Step Floating Catchment Area (3SFCA) method,

which is a recent addition to the family of gravity based accessibility measures, is applied to calculate the spatial accessibility at the neighbourhood level in the selected 14 Canadian Urban Areas (Bell, et al., 2013; Bissonnette, et al., 2012). In the second step, the intra-urban variations in spatial accessibility to PHC is investigated using GIS and spatial statistical tools. Comparative analysis between the urban settings is also performed for better understanding of accessibility to PHC services at the national level. The relationship between the geographical accessibility to PHC services and socio-demographic characteristics examined using global spatial regression method are further investigated for Calgary and Toronto cities by disaggregating the relationships at local scales and assessing the choice of geographical areal units for accessibility analysis.
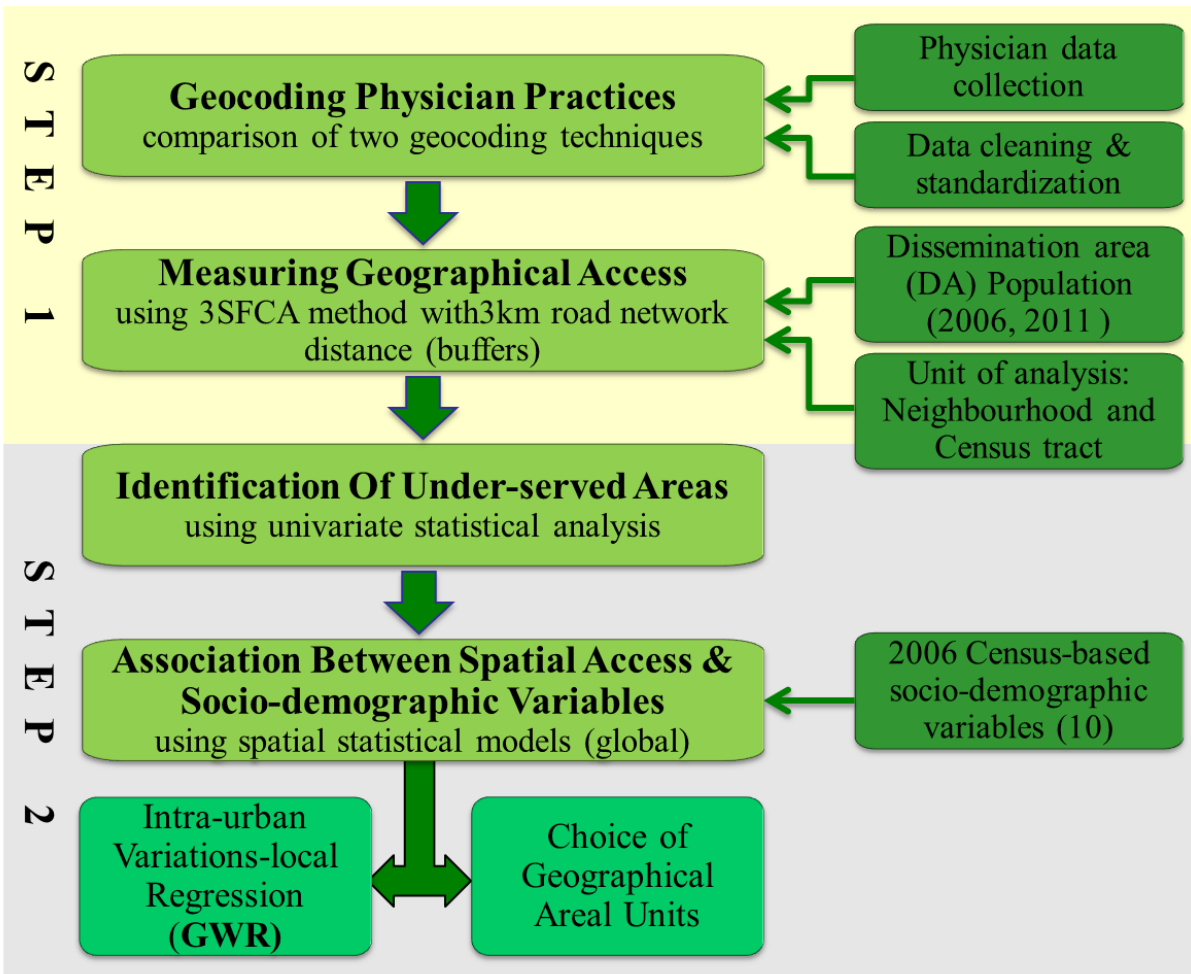
Figure 1-2. Research layout

Data and methods

This research took place in the 14 urban areas across Canada: Victoria and Vancouver, British

Columbia; Calgary and Edmonton, Alberta; Saskatoon, Saskatchewan; Winnipeg, Manitoba;

Hamilton, and Toronto, Ontario; Montréal and Québec City, Quebec; Halifax, Nova Scotia; St.

John's, Newfoundland; Saint John, New Brunswick; and Ottawa–Gatineau, Ontario and Quebec.

Each selected urban area is part of a corresponding CMA[5] for which locally relevant

neighbourhoods exist and represents all provinces where CMAs are located. The location map of

study areas in the Figure 1-1 shows the nationwide coverage. The CMAs have distinct

characteristics: population density, population per census tract, and population growth or decline

rate that may shape access to health care in different ways in these urban areas. These 14 urban

areas have been selected for comparative purposes across Canada and to assess the variations in

access to primary health care services at the neighbourhood levels. Among the study sites,

Toronto has highest population (5.113 million) and population density (866.1 population per

square kilometer) whereas Saint John's has lowest population (0.122 million) as well as lowest

population density (36.4). Two urban areas are selected from each of the following provinces;

Alberta, British Columbia, Ontario and Quebec based on the population density and other

distinct characteristics.

The Canadian Medical Association, in partnership with the College of Family

Physicians of Canada (CFPC) and the Royal College of Physicians and Surgeons of Canada, has

conducted the National Physicians Survey (NPS) every three years since 2004. The NPS

responses provide a comprehensive picture of physicians in a number of different topic areas

such as access, workload, types of services provided, remuneration, use of technology, future

plans, satisfaction levels and educational experiences. For this study, addresses and related

information of family physicians and general practitioners (primary health care service

providers) was collected from national and provincial sources such as provincial colleges of

physicians and surgeons, National Physicians Survey, etc. to support mapping and spatial

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[5] The CMA as defined by Statistics Canada in 2006 Census Dictionary has a total population of at least 100,000 of which 50,000 or more must live in the urban core.

analysis. A physician database (or physician inventory) was developed to handle this information. Brooker and Michael (2000) suggested that the development of any spatial database is meaningless unless there is a clear identification of the goals and definitions for using the information for informed decision making. Other related information, mail and email addresses, gender/sex, patient accepting status etc., was also gathered (where available). Data collection, downloading, coding, and analysis was conducted in the Spatial Analysis For Innovation in Health Research (SAFIHR, "Sapphire") lab at the University of Saskatchewan.

Population and social-demographic information was collected at various levels such as Census sub-division (CDS), census tract (CT), dissemination areas (DA), etc. Population figures come from the 2006 and 2011 Canada census whereas social-demographic variables were based on 2006 census data only. It is noted that 2006 census data is used to study the relationships among the socio-demographic factors and geographical accessibility to PHC services because of following reasons. First, 2011 National Household Survey (NHS) data at smaller statistical units such as DA, CT, etc., was not released at the time of analysis[6]. Second, research highlights the limitations of using the 2011 voluntary NHS data such as data suppression of data due to low quality, data not available for 25 percent (of 4,567) CSDs (Bell & Wei, 2014; Community Development Halton, 2013; Post, 2013; Walton-Roberts et al., 2014). The following supporting datasets for each study area was gathered through Sapphire; digital geographic boundary file for neighborhoods, demographic data for the residents of each urban area, digital geographic file of the 2006 Canadian Census for DAs, and road/street network for geo-coding purposes (to plot the location of health care service providers) as well as to generate network buffers for the 3SFCA method.

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[6] http://www12.statcan.gc.ca/nhs-enm/2011/rt-td/rt-td-eng.cfm

Various GIS techniques (e.g., spatial statistics, spatial autocorrelation, etc.) were applied to conduct the research. The following software was used to calculate accessibility at the neighbourhood level and to examine the association of accessibility with socio-demographic factors as well: ArcGIS 10.x, SPSS, MS Access, MS excel, and GeoDa. The three-step floating catchment method (Bell, et al., 2013; Bissonnette, et al., 2012), which is a modified form of 2SFCA method (Luo, 2004; Luo & Wang, 2003) was applied to measure the spatial access to PHC services (as shown in the flow diagram below, see Figure 1-2). The 2SFCA method is generally applied on census units of analysis and has yet to be used on neighbourhood units that are relevant to the local population and used for policy implementation (Bell, et al., 2013; Bissonnette, et al., 2012).

Step 1	Step 2	Step 3
• Physician –To-population Ratios (number of physicians per 1,000 populations) • Creating Catchment areas based on the road network distances • Ratios by counting the number of physicians at a given facility and the population of all DA centroids that fall within the catchment	• Points Of Health Care Demand • (the facility ratios are summed for a DA ratio of per 1,000) • DA centroids as the point of demand. • Catchment areas around DA centriods and based on road network distances • The ratios of all facilities falling within these DA catchment are summed for a given DA	• Units Of Analysis-neighbourhoods • (overall physician to population ratio • By averaging the ratios of all DA's that have centroids which fall within a given neighbourhood. • Note: first two step as follows the the 2SFCA (Luo, 2004), third step modified and introduced by (S. Bell, Wilson, Bissonette, et al., 2012; Bissonnette, et al., 2012a).

Figure 1-3. Three-Step Floating Catchment Areas method flow diagram

Organization of this Dissertation

This first chapter provides a brief overview of the access to primary health care in the context of Canadian health care system, introduces the research objectives, and a brief discretion of the research design. Next five chapters of this dissertation are organized into manuscript format. Chapter 2 describes the data preparation procedure particularly the geocoding technique applied to get the geographic coordinates (latitude and longitude) of primary health care services to address the research objective of this study. The purpose of this research was to compare the geocoding completeness and positional variability for 5,086 PHC services and an integrated geocoding procedure (i.e, a set of geocoding methods) was applied to PHC practices for increasing match rates with reduced positional uncertainty. Chapter 3 addresses the first two objectives of this research by measuring the spatial accessibility to PHC services and identifying the areas (or communities) having poor geographical access to primary health services. An index of spatial access to PHC services (i.e., accessibility score) using the 3SFCA method was calculated at locally defined neighborhoods. A comparison of accessibility score to simple physician-to-population ratio was provided in this research. Further, spatial statistical techniques was applied to analyze the spatial patterns of accessibility score at neighbourhood level among 14 urban settings. In chapter 4, the relationship between the geographical accessibility to PHC services and socio-demographic characteristics is examined which is helpful in examining the distribution of PHC services with respect to population health needs across 14 Canadian urban areas. To model this relationship, a spatial regression method is applied.

Chapter 5 and 6 present a case study of geographically weighted regression (GWR) in which the intra-urban variations in the relationships among the socio-demographic factors and geographical accessibility to PHC services are investigated. These chapters are focused on two

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Canadian urban areas (Calgary, AB and Toronto, ON). Chapter 5 highlight the significance of local spatial regression in disaggregating the relationships between socio-demographic variables and the geographical accessibility to PHC services at a local scale. Chapter 6 is focused on the choice of geographical areal units for accessibility analysis and investigates whether the associations between accessibility score and predictors vary in using different units of analysis.

The last chapter (Chapter 7) concludes the dissertation by summarizing the key findings and conclusions presented in the preceding sections. The policy implication and recommendations for future research are also discussed in this chapter.

CHAPTER 2: FIRST MANUSCRIPT

GEOCODING FOR PUBLIC HEALTH RESEARCH: EMPIRICAL COMPARISON OF TWO
GEOCODING SERVICES APPLIED TO CANADIAN CITIES

Authors: **Shah, T. I.**, Bell, S., & Wilson, K.

TS conceived and designed the study with SB, assembled input data, analysed and interpreted the data, and wrote the manuscript.

Chapter 2 describes the data preparation procedure particularly the geocoding technique applied to get the geographic coordinates (latitude and longitude) of primary health care services to address the research objective of this study. The geographic locations of PHC services play are an important role in measuring geographic accessibility to PHC services and using geocoding methods without considering their pros and cons could affect the actual estimates. The purpose of this research was to compare the geocoding completeness and positional variability for 5,086 PHC services and an integrated geocoding procedure (i.e, a set of geocoding methods) was applied to PHC practices for increasing match rates with reduced positional uncertainty.

This chapter is also a continuation of my previous work (as coauthor) on this topic. For more details on my other work, see Appendix B.

CHAPTER 2
GEOCODING FOR PUBLIC HEALTH RESEARCH: EMPIRICAL COMPARISON OF TWO
GEOCODING SERVICES APPLIED TO CANADIAN CITIES

Abstract

The process of geocoding, particularly the street address matching process, is a commonly used technique to obtain locational information for public health research. In health care accessibility research geocoded locations of health care providers are an essential element for measuring potential access to health care. Our objective is to compare the geocoding match rates and positional variation of two geocoding procedures by using street network and postal code datasets to geocode primary health care services in 14 cities. The first procedure uses a manually built geocoding service using DMTI Spatial (DMTI) reference datasets while the second employs an online geocoding service provided as a built-in tool in ArcGIS with ESRI Tele Atlas reference datasets. Results for Tele Atlas postal code and DMTI multiple enhanced postal codes (MEP) reference datasets produce much higher match rates (99.4%; 98.0% respectively); while results of Tele Atlas street dataset produce better match rates (96.5%) than the DMTI street dataset (90.0%). Geocoding methods using Tele Atlas and DMTI Street datasets produce more accurate locations than postal code and MEP reference datasets. Empirical comparison of the geocoding results based on manually built and online geocoding services highlight the need for integrated geocoding procedures for increasing match rates with reduced positional uncertainty.

Keywords: Urban geocoding, primary healthcare, health geography, automated geocoding, positional uncertainty

Introduction

In health research, geocoding plays an important role in determining geographical coordinates from postal addresses that can be used to study health care accessibility (Bell, et al., 2013; Bell, et al., 2012; Bissonnette, et al., 2012; Luo, 2004; Peipins et al., 2011; Schuurman, et al., 2010; Wan, Zhan, Lu, & Tiefenbacher, 2012), disease surveillance (Zinszer et al., 2010) and pattern detection (Wang et al., 2010), and risk analysis (Maantay, 2007; Samuel, Keren, Shelley, & Freeman, 2009). In the case of health care accessibility, locations of health care providers are a basic element in most methods for measuring potential access to health care. Address-match geocoding procedures are normally used to convert each postal address to a set of geographical coordinates. The concept of address matching is based on the comparison of two datasets; one containing address information for the sample of study (e.g., list of family physicians and their practice addresses), and the other a geographic reference dataset supported by address attributes (see Cromley & McLafferty, 2012, pp. 99-100). Address-match geocoding procedures can be accomplished in several ways; these methods include range interpolation, the areal unit model, and rooftop geocoding (Zandbergen, 2008; Zimmerman & Li, 2010). The primary method of street geocoding involves the relatively straightforward process (from a mathematical and geometric perspective) of using a geographical information system (GIS) to match an address along a continuous street segment based on the street address of a place and its position along the range of addresses for that street segment.

Many aspects of geocoding require attention to the quality of spatial datasets and postal addresses in order to generate reliable location data. The match rate and positional uncertainty of geocoded locations, which can indicate the reliability of these locations, depends on the accuracy of the postal address, reference data, and geocoding technique. In most research, an automated

process is applied to match all addresses with reference datasets, followed by manual editing to deal with unmatched addresses (Abe & Stinchcomb, 2008). Addresses that fail to match with the reference dataset may be the result of errors in the address record (a. missing street number, name, or type; b. error in street number, name, or type; c. not in a standard format), reference data (a. error in address range, missing range, on wrong side of street; b. street name, type; c. incomplete network topology), or due to incorrect side offsets (Boscoe, 2008; Cromley & McLafferty, 2012, p. 101; Zandbergen, 2009). In this study, we examine the match rates (i.e., completeness) and positional variation of geocoding physican practice sites with a focus on geocoding methods and geocoding errors normally associated with references datasets. The geocoding outcomes are combined to examine the possibilities for obtaining maximum match rates with reduced postionional uncertainty.

Evolution of Geocoding

The geocoding process as applied by researchers, geographers, and the lay public has undergone a substantial transformation. Every time a person enters an address into a GPS navigation system, google maps, or other online mapping system, they are relying on geocoding to generate a geographic coordinate from a street address (or similar). The proliferation of online geocoders using reference data similar to that used in stand-alone or GIS-based software such as ArcGIS provides powerful and accurate tools for converting single and multiple addresses to geographic coordinates. Not all such geocoders are equal and many online tools have experienced their own internal evolution. The geocoding process can be divided into four different but interconnected components (Goldberg, Wilson, & Knoblock, 2007; Roongpiboonsopit & Karimi, 2010a). The

input component consists of a single address or multiple addresses that are to be geocoded. The second component comprises the reference datasets that provide the source for geographic locations, including both address ranges and coordinates of individual block vertices. Important changes to the reference data aspect of geocoding have occurred in recent years. With the emergence of publicly available global mapping system (Google Earth/Map, Bing maps, etc.) and subsequent street level imagery and data, new geocoding methods not associated with range interpolation have emerged. In the case of Google Earth such point level reference data supports "rooftop" level geocoding in which a discrete (and not interpolated) coordinate pair is available for an address. The third component is a set of algorithms used to transform the input into a style compatible with the reference data. Finally, the output component is a geographical representation of the input in a point or object format, consisting of global absolute coordinates (e.g., latitude/longitude, UTM, etc.).

Traditionally, geocoding consisted of a user building a geocoding service by using reference datasets and by selecting the geocoding algorithms (parameters available in GIS software), or sometimes coding the algorithm themselves. Such geocoding is not user-friendly and a user has to acquire, maintain, and sometimes update their reference datasets. In this context, some studies demonstrating variability in geocoding match rates have compared results using manually built address locators with point, line, and parcel reference datasets in ArcGIS software (Zandbergen, 2008), or using Mapmaker Plus Version 6.0 with software's street reference file (Cayo & Talbot, 2003). In contrast, online geocoding that emerged with advancements in internet technology is quite different and mostly user friendly. Nowadays, online geocoding services can be accessed through web interfaces such as Geocoder.us, Yahoo, MapQuest, Google, Batchgeo, etc. However, there is still variability in positional accuracy and

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matching rates between the web-based geocoding services. For example, one study comparing five web services found that Google, MapPoint, and Yahoo web services produced more accurate points and less positional errors than Geocoder.us and MapQuest (Roongpiboonsopit & Karimi, 2010a). Online geocoding services can also be accessed through Desktop GIS software (e.g., ArcGIS, MapInfo, etc.). For example, some studies have used the ESRI geocoding tool in ArcGIS with different reference datasets (Bell, et al., 2012; Zhan, Brender, De Lima, Suarez, & Langlois, 2006) and also compared results with the BatchGeo online geocoding service (Duncan, Castro, Blossom, Bennett, & Gortmaker, 2011). Despite their widespread uptake, users often overlook the potential for changes to such systems over time and their general lack of clarity concerning accuracy. For instance, BatchGeo, formerly Batchgeocode.com, has undergone several unpublicized iterations over its history. These iterative changes can be the result of legal conflict between their service and the API provider, changes in the API itself (necessary to generate geocoding results), or stem from business requirements. For instance, in its earliest form the output included both X, Y coordinates and accuracy output (type of geocoding used for each location: place centroid [city, region, etc.], range interpolated, rooftop, etc.). In its current form (March, 2014), accuracy information is not provided and X, Y coordinates are only available if the raw KML output is edited manually. This is just one example of the dynamic nature of the online geocoding landscape.

An important caveat for several of the above methods, in particular any method that uses an reference dataset, is that these methods rely on sending address data from the input file over the internet to a remote location for processing. This step has considerable ethical implications for researchers using confidential data or data that contain personal information. Furthermore, researchers need to be sensitive about where data are sent and how they are stored

and returned. Many online services store data in remote locations in different jurisdictions (countries) that might have different judicial restrictions or expectations for health, personal, or similar information. Despite technological advances and increasing ubiquitous availability of geocoding services, it is very likely that researchers will continue to use locally stored reference data to protect confidential data and maintain compliance with ethical requirements (Cromley & McLafferty, 2012, pp. 259-261; Curtis, Mills, & Leitner, 2006; Goldberg, 2008, p. 43).

In this study, our focus is on the practice location of primary health care (PHC) providers; they play an important role in the delivery of health care in Canada and are therefore a good measures of accessibility to healthcare. The purpose of this study is twofold: 1) to compare the results of manually built and online geocoding services using different reference datsets in geocoding the addresses of PHC services (i.e., physician practice sites) in Canadian urban settings, and 2) to combine results to increase geocoding match rates while not reducing spatial accuracy. The results will not only inform our understanding of accessibility in the 14 cities included here, it will also provide guidelines for generating similar metrics in the future and in different locations. In all cases we employ what we consider best practices in data preparation and geocoding; this includes preprocessing in order to anticipate and alleviate potential geocoding errors or mismatches. Preprocessing is used to correct known errors in the input data and regularize" its format (Bell, 2012b).

Methods

Study area

Geocoding completeness and positional uncertainty is examined for 14 urban areas across
Canada: Victoria and Vancouver, British Columbia; Calgary and Edmonton, Alberta; Saskatoon,
Saskatchewan; Winnipeg, Manitoba; Hamilton and Toronto, Ontario; Montréal and Québec City,
Québec; Halifax, Nova Scotia; St. John's, Newfoundland; Saint John, New Brunswick; and
Ottawa–Gatineau, Ontario and Québec (see Figure 2-1). Each urban area consists of at least one
Census subdivision[7] (or municipality) and is part of a corresponding Census Metropolitan Area
(CMA)[8] for which locally relevant neighbourhoods exist. The urban areas have distinct
characteristics, such as population size (varying in size from a low of 196,966 in St. John to a
high of 2,615,060 in Toronto) and population density (ranging from 71 persons per square
kilometer in Halifax to 4149 in Toronto) (see Table 2-1). These urban areas have been selected
for comparative purposes and represent all provinces with CMAs.

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[7] Census subdivision (CSD) as defined by Statistics Canada in the 2011 census as "the general term for
municipalities (as defined by provincial/territorial legislation) or areas treated as municipal equivalents for statistical
purposes (e.g., Indian reserves, Indian settlements and unorganized territories)."
[8] The census metropolitan area (CMA) as defined by the Statistics Canada in 2011 census is "one or more adjacent
census subdivisions (or municipalities) gathered around a core (of population) having a total population of at least
100 000 and out of which 50 000 or more must located with the core area."

Table 2-1. Population Densities for 14 Urban Areas

Province	Urban Area	2011 Census subdivisions/Municipalities			
		Count (n)	Population	Area (km2)	Population Density (per/square km)
Alberta	Calgary	1	1 096 833	825	1329
	Edmonton	2	873 667	733	1192
British Columbia	Vancouver	3	892 696	221	4036
	Victoria	9	280 373	214	1312
Manitoba	Winnipeg	1	663 617	464	1430
New Brunswick	Saint John	4	105 013	468	225
Newfoundland and Labrador	St. John's	13	196 966	805	245
Nova Scotia	Halifax	1	390 096	5490	71
Ontario	Hamilton	3	721 053	1372	526
	Toronto	1	2 615 060	630	4149
Québec	Montréal	16	1 886 481	499	3779
	Québec City	4	672 136	913	736
Ontario / Québec	Ottawa - Gatineau	2	1 148 740	3133	1091
Saskatchewan	Saskatoon	1	222 189	210	1060
Grand Total		61	11 764 920	15 976	736

Note: n represents the number of municipalities in an urban area selected for this research.
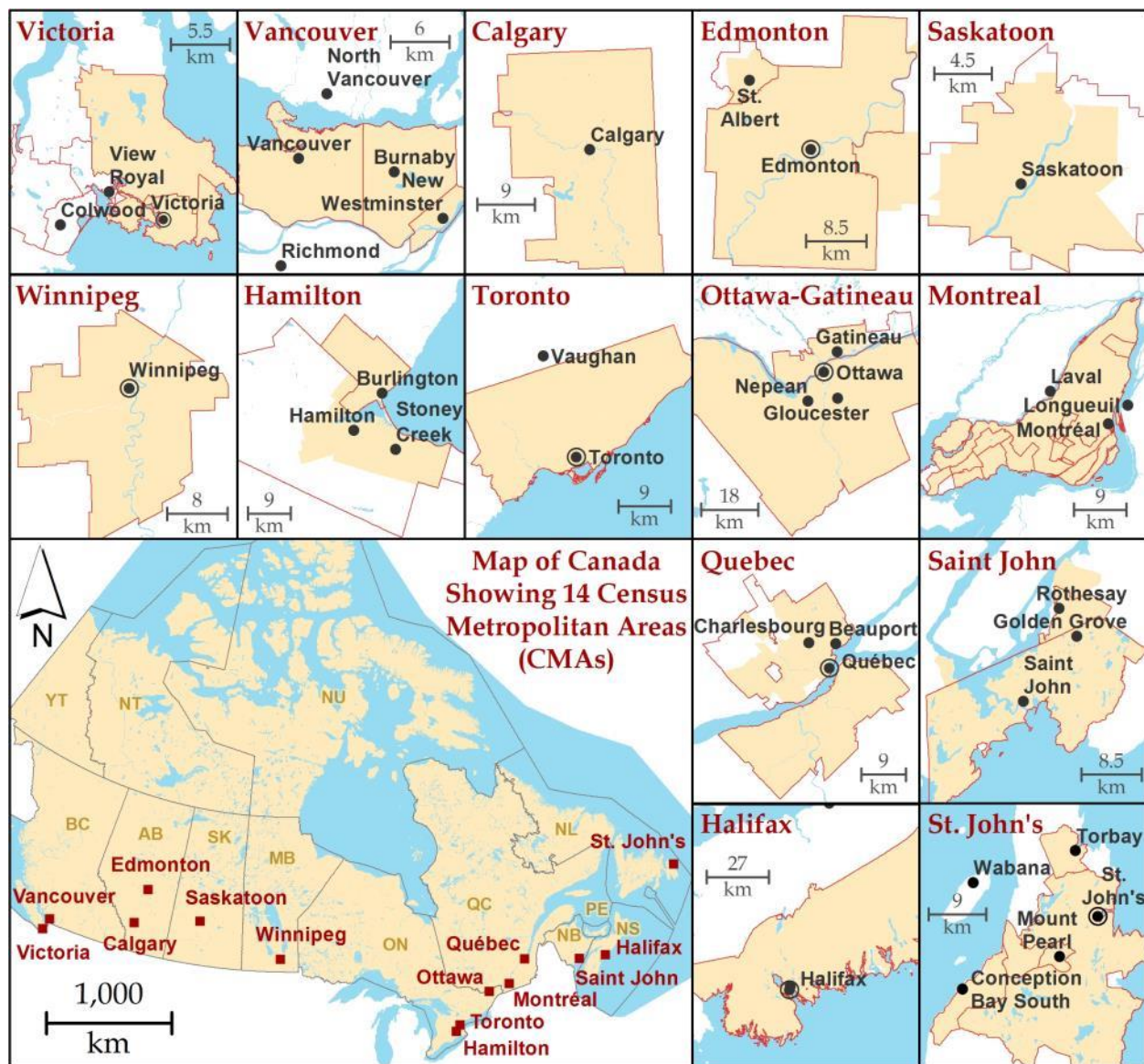
Figure 2-1. Study area map

Data and methodology

The input data consisted of physicians' addresses retrieved from individual profiles collected via

Provincial Colleges of Physicians and Surgeons (see Table 2-2 for information about data

sources and acquisition dates); these data were used to prepare information for physician practice

sites. Only those physicians specified as Family Doctors, Family Physicians, General

Practitioners, or Non-Specialists were included in the physician practice inventory; furthermore, we excluded physicians not directly involved in providing primary care (e.g., physicians doing non-clinical jobs with College of Physicians and Surgeons of Alberta [CPSA], Canadian Medical Association [CMA], Health Regional office, etc.,), or those providing care at a hospital location. Physicians can have multiple practice sites within the same municipality (census subdivision) or any other area including other municipalities, cities, provinces, or even countries. It is important to mention that only those physicians who have their primary practice site within the municipal boundaries of the study areas examined were considered. All physician data was downloaded between July 2010 and October 2011(see Table 2-2).

Table 2-2. Information on the practice addresses of primary health care (PHC) providers

Province	City	Acquisition Date	Source
Alberta	Calgary	August, 2010	(CPSA (College of Physicians and Surgeons of Alberta), 2010)
	Edmonton	August, 2010	
British Columbia	Vancouver	July, 2010	(CPSBC(College of Physicians and Surgeons of British Columbia), 2011)
	Victoria	July, 2010	
Manitoba	Winnipeg	August, 2010	(CPSM (College of Physicians and Surgeons of Manitoba), 2010)
New Brunswick	Saint John	July, 2010	(CPSNB (College of Physicians and Surgeons of New Brunswick), 2010)
Newfoundland & Labrador	St. John's	August, 2010	(CPSNL(College of Physicians and Surgeons of Newfoundland and Labrador), 2011)
Nova Scotia	Halifax	November, 2011	(CPSNS (College of Physicians and Surgeons of Nova Scotia), 2011)
Ontario	Hamilton	May, 2011	(CPSO (College of Physicians and Surgeons of Ontario), 2011)
	Toronto	May, 2011	
Québec	Montréal	December, 2010	(CMQ (Collège des médecins du Québec), 2010)
	Québec City	December, 2010	
Ontario/Québec	Gatineau	December, 2010	(CMQ (Collège des médecins du Québec), 2010)
	Ottawa	May, 2011	(CPSO (College of Physicians and Surgeons of Ontario), 2011)
Saskatchewan	Saskatoon	July, 2010	(CPSS (College of Physicians and Surgeons of Saskatchewan), 2010)

In Canada, address information required for street address geocoding should comprise the following four fields: street address, city/municipality, province, and forward sortation area (FSA; first three digits of Canadian postal code). In the geocoding process, it is very important to have an accurate, precise, and consistent address inventory- something not always available. For this purpose, a single common MS Excel file for physician practice inventory was prepared using physician profile data collected at the provincial level. A series of pre-processing steps necessary for selection of a representative subset, data compilation (including data aggregation), and data standardizing (Duncan, et al., 2011), were applied as explained below.

First, a Municipality field based on the existing "City" field was added to the physician dataset and city names were updated by consulting FSA and Statistics Canada information. This was done because the existing "City" field in the college directories contains some older municipality names (e.g., Toronto can be referred to as City of Toronto, East York, Etobicoke, North York, Scarborough, and York), town names (e.g., Weston, Willowdale, etc.), community, and other area names which have since been absorbed into the study municipalities. Addresses outside the selected census subdivisions/ municipalities were removed from the physician address inventory. This step was only possible because of the relatively small sample size and regularity of the records; each record was associated with one of 14 metro areas. While this step is not generally associated with the geocoding process and most researchers do little pre-processing before sending their addresses to a geocoder, we believe this represents a serious oversight. Such "shortcutting" may result in both Type I (address generates a geographic location, but location is incorrect) and Type II (not geocoded) errors. The additional preprocessing is not prohibitive in small datasets (< 10,000 records) and involves data

exploration and cleaning similar to that undertaken during initial stages of analysis with any new and unfamiliar dataset.

   Second, addresses were removed that had only Post Office Box (P.O. Box) information (see Table 2-3); a P.O. Box address does not represent a physician's actual practice address and their inclusion could increase geocoding error. They are also more likely to represent locations distant from the actual location of health care delivery (Zandbergen, 2009). After removing records having no proper and relevant address (P.O. Box, outside the study areas, under hospital and/or administration category, etc.), there were 11,561 physician locations (see Table 2-3) selected for further data cleaning and analysis.

Table 2-3. Physicians count categorized by their practice addresses

Study Area	Category	Number of Physicians
Included	Street Address	11 534
	No Street Number	18
	Postal Code Only	9
	Total	11 561
Not Included	P.O. Box	202
	No Address	68
	Outside the study area	79
	Hospital/Administration	2938
	Total	3287
	Grand Total	14 848

Third, street address cleaning and standardization was done by moving all unnecessary characters into another field (e.g., suite numbers), removing most punctuation (e.g., commas, quotation marks, etc.), and converting all street types and directions to abbreviations used in DMTI products and Canada Post address guidelines (Canada Post, 2011). As the focus of this study is to evaluate the performance of different geocoding techniques in preparing physician practice locations, the second and third steps are crucial for both selection of representative subset of a large database (e.g., a representative subset of physician practice locations within Toronto municipality area from a provincial level physician directory/dataset) and for data compilation. They represent best practices in geocoding, particularly when accurate location results are desired (Goldberg, 2008, p. 51; Zandbergen, 2008). It is our belief that straightforward work in the pre-processing stage is essential to reliable and valid geocoding. Relying on automated tools for address parsing is dangerous as it can be difficult to assess whether an "accurate" geocoding result (i.e., a positive match) is in fact an accurate result. Too many researchers relying on geocoding only concern themselves with the "tied" and "unmatched" results from a geocoding session, accepting as truth all "matched" addresses.

Fourth, the physician practice inventory (i.e., physician common addresses) was prepared by aggregating physician practice addresses using the PivotTable tool available in MS Excel software. This step consolidated all physicians at a single practice to a single address record. Based on the physician inventory (or individual profiles), a list of 5,086 physician practice sites[9] (for the 11,561 physicians identified) in the 14 study areas was finalized for geocoding purposes.

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[9] Note: 37.8 percent of total practice sites (i.e., 1924 out of 5,086) are identified as group practices where 72.6 percent of total physicians (i.e., 8,399 physicians) were working.

Geocoding methods

To determine the geocoding match rates and positional variations, PHC practice addresses from 14 urban areas were geocoded using four different reference datasets. As discussed earlier, a geocoding process consists of four different but interconnected components. For this research, a single file having 5,086 physician practice addresses from 14 urban areas is the input component. The second component, that provides the reference for geographic locations, is taken from two differently maintained spatial datasets. The third component, that transforms input addresses into a style compatible with the reference data, is based on an online geocoding service and manually built address locators. The first two layers (A and B, given below) are created using the ArcGIS online geocoding service and the last two layers (C and D, given below) are created using manually built address locators based on DMTI Spatial's (DMTI) reference datasets as described below. The output component of the geocoding process is a point layer that is a geographical representation of input data.

*Tele Atlas (ESRI) street layer (A).*This layer was created using the online geocoding service in ArcGIS 10 and Tele Atlas CANStreet from ESRI as the reference street data. Tele Atlas is a value-added product based on Statistics Canada street file data. In this method, the address locator utilizes the Street address, Municipality, Province, FSA, and Country fields with geocoding settings (see Table 2-4). Geocoding results shown in Table 2-5 are based on four different address locators (i.e., CAN_CityProv, CAN_StreetName, CAN_Streets[10], and CAN_Rooftop) reported in the outcome layer that are automatically involved by the software during the geocoding process. The geocoded results based on CAN_Streets, and CAN_Rooftop

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[10] Includes both street name and number.

address locators with match scores at or above 80 percent (see, Duncan, et al., 2011; Yang, Bilaver, Hayes, & Goerge, 2004; Zandbergen, 2011) were accepted for further analysis.

*ESRI postal code layer (B).*This layer was created using an online geocoding service in ArcGIS 10 and Tele Atlas postal codes from ESRI as the reference data. Settings for this geocoding method are given in Table 2-4. The geocoded results with match scores at or above 80 percent were accepted for further analysis.

*DMTI street layer (C).*This layer was created using a geocoding service manually built using DMTI CANmap Streetfiles (DMTI Spatial, 2011a) as reference data. In this method, the address locator utilizes the Street address, Municipality, Province, FSA, and Country fields with geocoding settings as mentioned in Table 2-4. The geocoded results with match scores at or above 80 percent were accepted for further analysis.

*DMTI multiple enhanced postal codes (MEP) layer (D).*This layer was created using a geocoding service manually built using DMTI MEP, a precision point file (DMTI Spatial, 2011c), as reference data. Settings for this geocoding method are given in Table 2-4. The geocoded results with match scores at or above 80 percent were accepted for further analysis.

For all geocoding methods, tied addresses with a minimum match score at or above 80 percent (see Table 2-5) were resolved by consulting online sources (e.g., Google Maps, ESRI Open Street Maps) in conjunction with the interactive re-matching tool in ArcGIS. Finally, the results of different geocoding methods were merged together to evaluate combined match rates. For this purpose, we applied two sets of results. First, we merged the results of all four methods.

For remaining results, we used the following combinations: any three methods, any two methods, and any one method. Second, the results of geocoding match rates were merged via pairwise combinations based on use of the same reference dataset (i.e., street network and point) and the same type of data sources (i.e., DMTI and ESRI datasets).

Table 2-4. Geocoding Data and Manual Settings

Layer	Spelling sensitivity	Minimum candidate score	Minimum match score	Side Offset	End Offset
Tele Atlas Street	60	40	85	n/a*	n/a
ESRI Postal Code	60	40	85	0	0
DMTI Street	60	40	85	20 ft	3%
DMTI MEP	60	40	85	0	0

* Not applicable

Table 2-5. Automatically generated results – four different geocoding methods

Geocoding method	Matched	Tied	Unmatched
ESRI Tele Atlas Street	5067 (100%)	17 (0%)	2 (0%)
ESRI Postal code	4982 (98%)	0 (0%)	104 (2%)
DMTI Street	4598 (91%)	7 (0%)	481 (9%)
DMTI MEP	4783 (94%)	271(5%)	32 (1%)

Results

In this study, we compared the results of geocoding match rates using different types of reference datasets and data sources in urban settings. We also combined the results of different geocoding methods to explore the possibilities for getting maximum match rates. In the next stage, we

calculated the distances between the geocoded locations of a PHC service to determine the positional variation between methods.

Match rates

The geocoding match results of 5,086 addresses of PHC providers in the 14 study locations are found in Table 2-6 (see also Figure 2-2). Addresses geocoded with a match score at or above 80 percent (see Duncan, et al., 2011; Yang, et al., 2004; Zandbergen, 2011) are included in the calculation of match rates. Results are broken down by urban area and geocoding methods. Overall, match rates for all geocoding methods are quite high, with most greater than 90 percent. When comparing the reference datasets, the match rates reported for the postal code (98.0 percent) and MEP (99.4 percent) datasets are better than those found for Tele Atlas (96.5 percent) and DMTI (90.5 percent) street datasets.

As for geocoding match rates of urban area addresses, results of geocoding methods using ESRI postal code and DMTI MEP reference datasets are very close in all cases (96.8 – 100 percent in both methods, see Table 2-6) except for in Saskatoon, which has zero matches with the ESRI postal code reference dataset because it is incomplete. The maximum match rate difference is found in Halifax where the match rate for Tele Atlas street dataset (96.4 percent) is 25.4 percent higher than DMTI Street (71.0 percent). Results for the Tele Atlas street dataset in all urban areas (ranging from 88.5 to 99.5 percent) are relatively higher (except in Edmonton) than the DMTI Street dataset (ranging from 71.0 to 96.9 percent). In comparison with population densities, match rates (ESRI Tele Atlas Street and DMTI Street) using street reference data are better in urban areas with higher population density (Spearman's rho = 0.511 and 0.589; p-value

= 0.026 and 0.010 respectively). In contrast, no such correlation is found in non-street methods

(Spearman's rho = 0.269 and 0.087; p-value = 0.176 and 0.379 respectively).
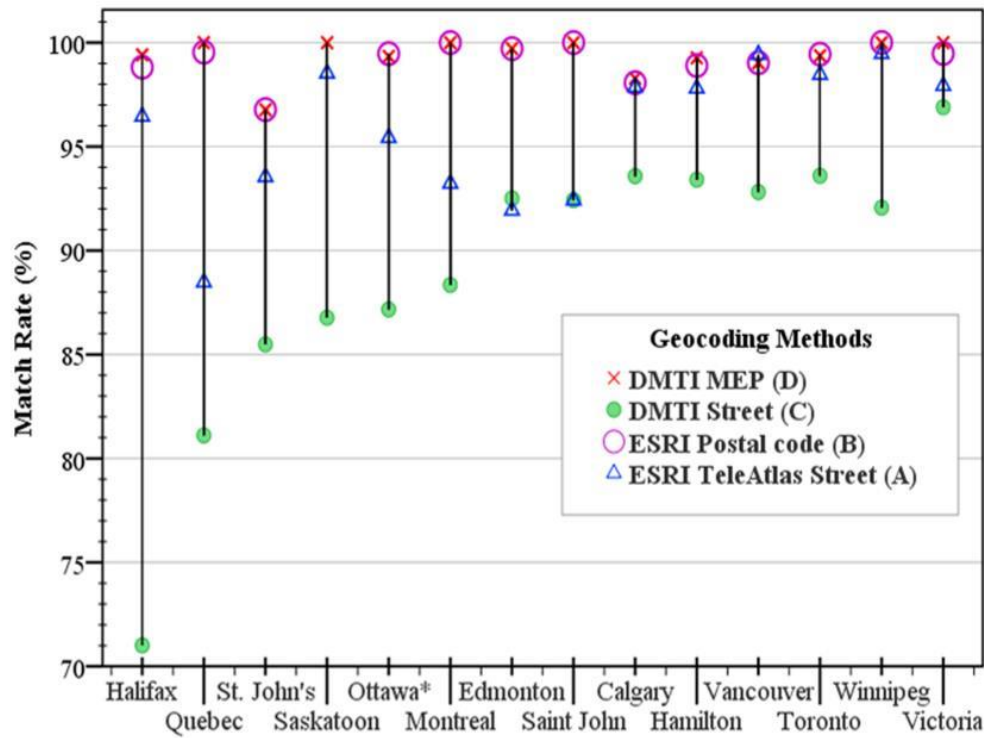
Figure 2-2. Geocoding match rates of the four methods by urban areas (* Ottawa-Gatineau)

Table 2-6. Geocoding match results (score ≥ 80) of the four methods by urban areas (number and percentage)

Province	Urban Area	Address	A-ESRI Tele Atlas Street Matched		B-ESRI Postal code		C-DMTI Street		D-DMTI MEP	
		Number	Matched	%	Matched	%	Matched	%	Matched	%
AB	Calgary	467	457	(97.9)	458	(98.1)	437	(93.6)	459	(98.3)
	Edmonton	347	319	(91.9)	346	(99.7)	321	(92.5)	346	(99.7)
BC	Vancouver	515	512	(99.4)	510	(99.0)	478	(92.8)	510	(99.0)
	Victoria	193	189	(97.9)	192	(99.5)	187	(96.9)	193	(100.0)
MB	Winnipeg	189	188	(99.5)	189	(100.0)	174	(92.1)	189	(100.0)
NB	Saint John	66	61	(92.4)	66	(100.0)	61	(92.4)	66	(100.0)
NL	St. John's	62	58	(93.5)	60	(96.8)	53	(85.5)	60	(96.8)
NS	Halifax	169	163	(96.4)	167	(98.8)	120	(71.0)	168	(99.4)
ON	Hamilton	273	267	(97.8)	270	(98.9)	255	(93.4)	271	(99.3)
	Ottawa-Gatineau	380	362	(95.3)	376	(98.9)	316	(83.2)	375	(98.7)
	Toronto	1437	1415	(98.5)	1429	(99.4)	1345	(93.6)	1428	(99.4)
QC	Montreal	635	592	(93.2)	635	(100.0)	561	(88.3)	635	(100.0)
	Ottawa-Gatineau	68	65	(95.6)	68	(100.0)	62	(91.2)	68	(100.0)
	Québec City	217	192	(88.5)	216	(99.5)	176	(81.1)	217	(100.0)
SK	Saskatoon	68	67	(98.5)	---	--	59	(86.8)	68	(100.0)
Overall values		5086	4907	(96.5)	4982	(98.0)	4605	(90.5)	5053	(99.4)

Combined geocoding match rates

Combined match rates of the geocoding methods in different combinations are shown in Tables 2-7a and b. The majority of physician practice sites (87.3 percent) are geocoded by all four methods used in this study (see Table 2-7a). Of the 645 remaining records, 511 practice sites (10.0 percent of total) are geocoded by three methods, 120 records (2.4 percent) by two methods, and 11 records (0.2 percent) by only one geocoding method. In the case of pairwise merging, a high of 97.9 percent of physician practice sites are geocoded in both geocoding methods using

postal code reference datasets (see, Table 2-7b). In a comparison of data sources, the pair of

ESRI Tele Atlas datasets achieved a higher combined match rate (94.6 percent). Results reveal

that maximum match rates could be achieved by merging the results of different geocoding

methods using different reference datasets; this results in the selection of a more accurate pair of

geographic coordinates and a confident decision regarding the positional differences/variation

between the geocoded locations.

Table 2-7a. Overall combined geocoding match rates

Number of Methods	Matching status	
	N = 5086	%
All four methods	4441	87.3%
Any three methods	511	10.0%
Any two methods	120	2.4%
Any one method	11	0.2%
None	3	0.1%

Table 2-7b. Combined geocoding match rates: results of geocoding match rates using same type of reference datasets and same type of data sources

Number of Methods	Both Street methods (AC)		Both Postal code methods (BD)		Tele Atlas (Street & Postal code (AB)		DMTI (Street & Postal code (CD)	
	N = 5086	%	N = 5086	%	N = 5086	%	N = 5086	%
Both methods	4524	89.0%	4980	97.9%	4809	94.6%	4584	90.1%
Any One	465	9.1%	75	1.5%	272	5.3%	490	9.6%
None	97	1.9%	31	0.6%	5	0.1%	12	0.3%

Positional uncertainty

To determine the positional variation/uncertainty of geocoded locations, we calculated distances between the locations of a PHC address generated using geocoding methods by applying the Euclidean metric[11]. There are many ways of calculating distance between two points (see Cromley & McLafferty, 2012, p. 313), but we selected the Euclidean metric because it computes the shortest distance between two. For this calculation between the pairs of geocoding methods, geocoded layers were transformed into a common coordinate system (i.e., North America Equidistant Conic). Figure 2-3 shows an example of measuring distances among four geocoded locations for a single clinic address. The distance between methods AB, AC, AD, BC, BD, and CD are 379 m, 250 m, 369 m, 264 m, 318 m, and 129 m respectively, which demonstrates positional variation in the geocoded locations. By considering the length of street segments, (larger segments are a possible source of geocoding error) and size of postal code regions (larger parcel size could increase positional error) in urban settings (Zandbergen, 2011), we considered the pairs with distances greater than 5000 m as outliers and they were removed from the calculation (see Table 2-8a). Overall, 114 geocoded records were removed. There were 58 pairs of ESRI Tele Atlas street and ESRI postal code (A-B) methods, 9 of ESRI Tele Atlas street and DMTI street (A-C), 45 of ESRI Tele Atlas street and DMTI MEP (A-D), 8 of ESRI postal code and DMTI street (B-C), 44 of ESRI postal code and DMTI MEP (B-D), and 7 of DMTI street and DMTI MEP (C-D). Over 70 percent of outliers were within the positional difference of 10 km (see Table 2-8b).

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[11] $[(X_1 - X_2)^2 + (Y_1 - Y_2)^2]^{1/2}$; where (X_1, Y_1) and (X_2, Y_2) represent the coordinates of two points in a pair.

Figure 2-3. Distance (Euclidean) differences between pairs of geocoding methods – an example of a small area (source: Microsoft's Bing Maps (Aerial Layer) with ArcGIS, March 12, 2013)
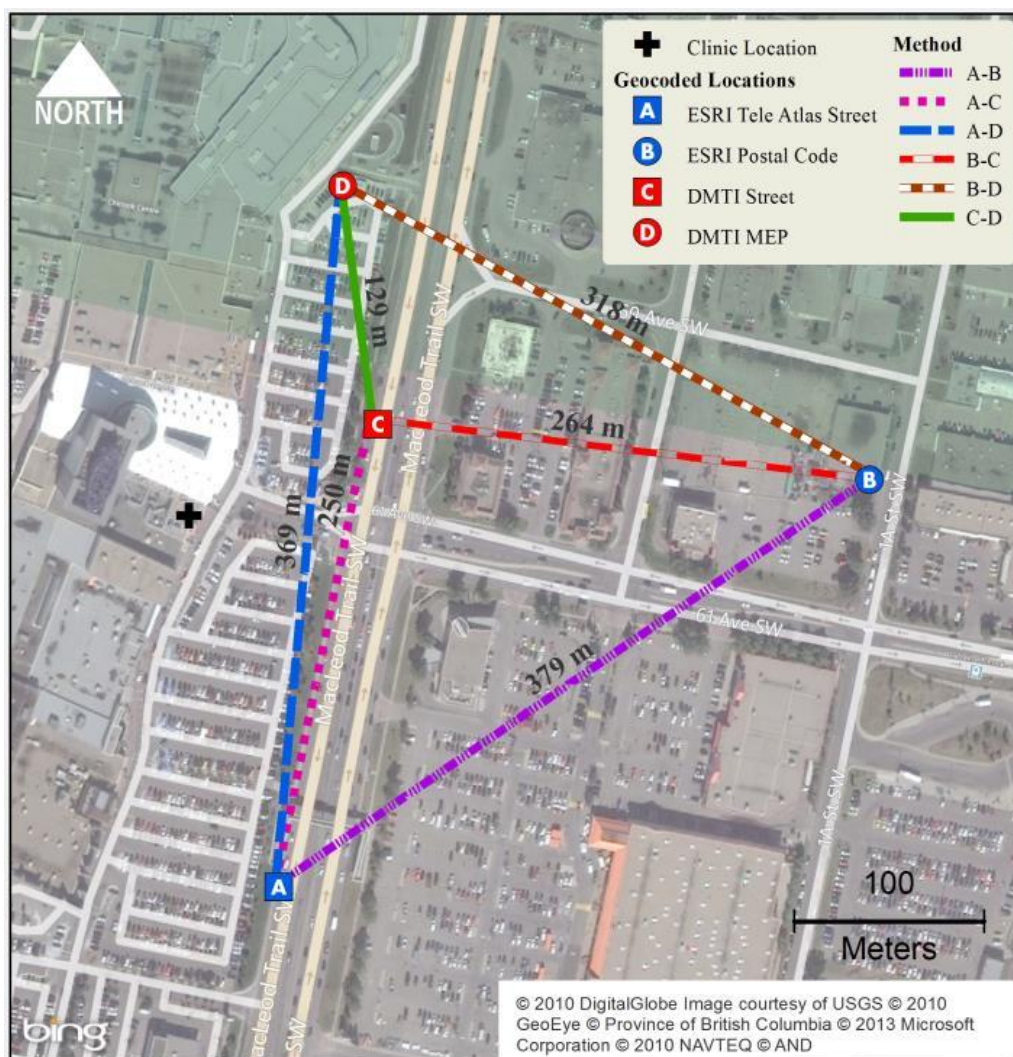
Table 2-8a. Distance differences greater than 5 km (outliers) between pairs of the geocoding methods

Urban Area	ESRI Tele Atlas Street- ESRI PC	ESRI Tele Atlas Street- DMTI Street	ESRI Tele Atlas Street- DMTI MEP	ESRI PC - DMTI Street	ESRI PC - DMTI MEP	DMTI Street - DMTI MEP
	(A-B)	(A-C)	(A-D)	(B-C)	(B-D)	(C-D)
Calgary	1		2		2	1
Edmonton	2		2			
Halifax	5		3	3	5	2
Hamilton	5		3		1	
Montreal	4		1		8	
Ottawa-Gatineau	19		12	3	22	1
Québec City	4		5	1	3	2
St. John's			1		1	1
Toronto	14	7	12	1	2	
Vancouver	3	2	3			
Victoria	1		1			
Total	58	9	45	8	44	7

Table 2-8b. Outliers: Distance differences intervals between pairs of the geocoding methods

Distance (meters)	ESRI Tele Atlas Street-ESRI Postal Code	ESRI Tele Atlas Street- DMTI Street	ESRI Tele Atlas Street- DMTI MEP	ESRI Postal Code - DMTI Street	ESRI Postal Code - DMTI MEP	DMTI Street - DMTI MEP
	(A-B)	(A-C)	(A-D)	(B-C)	(B-D)	(C-D)
0-5000	4,751	4,515	4,833	4,516	4,936	4,577
5000-10000	38	2	31	5	30	5
10000-15000	7	2	8	1	2	2
15000-20000	5	4	4	1	1	
25000-30000	1	1	1			
30000-35000	1		1			
>35000	6			1	11	
not included	277	562	208	562	106	502

Positional variation between the methods

Nationwide descriptive statistics of the distance differences calculated between the pairs of four methods are presented in Table 2-9 whereas descriptive statistics by urban areas appear in Table 2-10. The mean of distance differences (meters) between the methods AB, AC, AD, BC, BD, and CD are 157 m (SD 463 m), 59 m (SD 208 m), 127 m (SD 433 m), 149 m (SD 368 m), 161 m (SD 441 m), and 75 m (SD 282 m) respectively and are found to be statistically significant differences. The nationwide distance variation in intervals between the pairs of geocoding methods is displayed in Table 2-11. The results show that the geocoded locations using postal code reference datasets are more uncertain (12 percent of the locations have more than 200 m positional differences) than the locations using street datasets (3 percent of the locations have more than 200 m positional differences).

Overall, results of the methods using ESRI Tele Atlas datasets (street and postal code) display more positional differences (high mean, median and IQR values) than the methods using DMTI datasets. Results of the methods using postal code reference datasets (postal code and MEP) display more positional differences than the methods using street datasets (Tele Atlas and DMTI).

Error bars (95 percent CI) for the mean positional differences (meters) between the pairs of the geocoding methods (AB, AC, AD, BC, BD, and CD) by urban areas are displayed in Figure 2-4. Summary statistics of positional differences by urban areas are given in Table 2-9. The results of this analysis reveal significant variation between positional differences among urban areas. Positional differences of Winnipeg addresses geocoded using ESRI Tele Atlas datasets (between street and postal code, A-B) are found on the lowest end (mean 90 m) which

indicates less positional variation in the geocoded locations whereas St. Johns addresses are found on the higher end (mean 346 m). In the case of DMTI datasets (between street and MEP, C-D), positional differences of Vancouver are found to be lowest (mean 52 m) whereas Québec City addresses are on the higher end (mean 282 m). Positional differences of all urban areas geocoded using street reference datasets (Tele Atlas and DMTI, A-C) are found to be less than 100 m except in St. John's (128 m), whereas in postal code reference datasets (B-D) all urban areas are over 100 (except Toronto, 88 m) ranging from 102m in Winnipeg to 582m in Québec City. In all cases (AB, AC, AD, BC, BD, and CD), the following urban areas display less positional uncertainty in geocoding results: Toronto, Winnipeg, Montreal, Victoria, Edmonton, Vancouver, and Saskatoon.
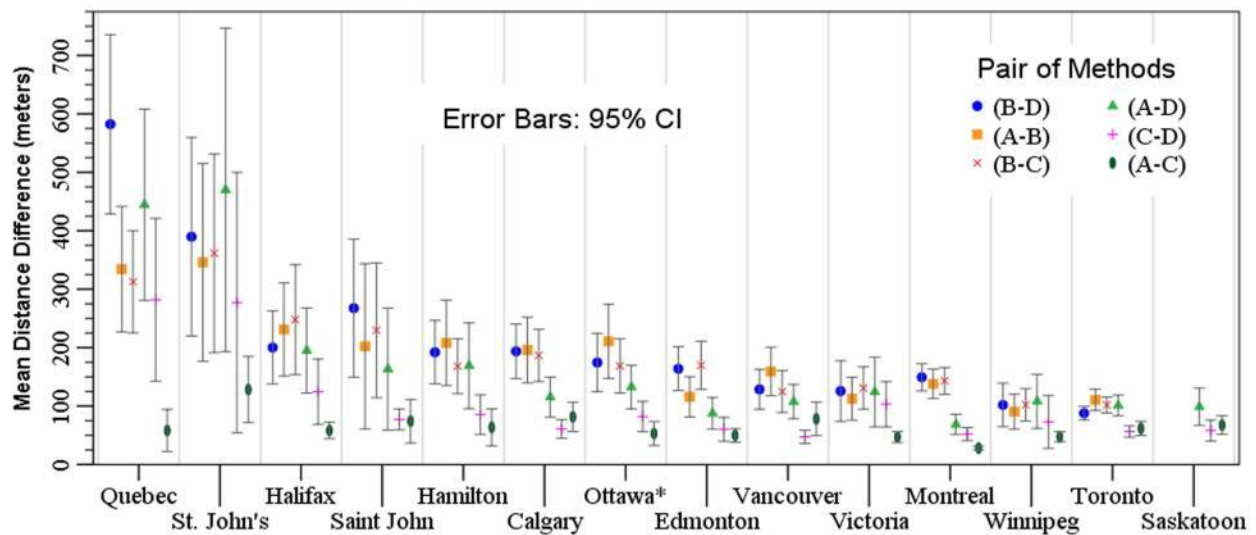
Figure 2-4. Error Bar of mean (Euclidean) distance difference between the pairs of the geocoding methods by urban areas (* Ottawa-Gatineau)

Table 2-9. Nationwide descriptive statistics of distance differences between the pairs of the geocoding methods

Descriptive Statistics (Nationwide)		ESRI Tele Atlas Street - ESRI Postal code	ESRI Tele Atlas Street - DMTI Street	ESRI Tele Atlas Street - DMTI MEP	ESRI Postal code - DMTI Street	ESRI Postal code - DMTI MEP	DMTI Street - DMTI MEP
		(A-B)	(A-C)	(A-D)	(B-C)	(B-D)	(C-D)
Count		4751	4515	4833	4516	4936	4577
Mean		157	59	127	149	161	75
Median		48	24	37	60	56	21
Std. Deviation		463	208	433	368	441	282
Minimum		0	0	1	0	0	1
Maximum		4,999	3,901	4,953	4,958	4,927	4,834
Range		4,999	3,901	4,953	4,958	4,926	4,833
IQ Range		81	46	64	108	81	46
Percentiles	5	6	3	7	5	12	4
	10	8	4	10	8	19	4
	25	20	8	17	22	30	11
	50	48	24	37	60	56	21
	75	102	54	81	131	110	57
	90	225	108	168	253	236	123
	95	557	161	337	531	589	201

Table 2-10. Descriptive statistics of distance difference between the pairs of the geocoding methods by urban areas

City	Statistics	Tele Atlas Street -Postal Code	Tele Atlas Street -DMTI Street	Tele Atlas Street - DMTI MEP	Postal Code - DMTI Street	Postal Code - DMTI MEP	DMTI Street - DMTI MEP
		(A-B)	(A-C)	(A-D)	(B-C)	(B-D)	(C-D)
Calgary	Count	447	432	447	429	456	428
	Mean	196	81	115	187	194	61
	Median	55	41	48	80	71	22
	SD.	605	265	370	473	508	166
	Min.	2	1	3	2	3	1
	Max.	4,530	3,759	4,502	4,087	4,827	2,901
	IQ Range	74	56	58	100	86	59
Edmonton	Count	316	301	316	321	346	321
	Mean	116	50	87	170	164	60
	Median	45	26	40	71	68	19
	SD	311	103	246	376	354	187
	Min.	2	0	2	0	3	4
	Max.	3,072	1,415	3,136	3,442	3,409	2,304
	IQ Range	69	44	53	99	88	43
Halifax	Count	156	118	159	116	162	118
	Mean	231	58	195	248	200	124
	Median	48	28	52	88	63	20
	SD	505	78	465	511	403	306
	Min.	1	0	4	1	6	4
	Max.	3,017	473	2,958	3,229	2,574	2,116
	IQ Range	181	82	117	169	100	63
Hamilton	Count	259	253	262	253	269	254
	Mean	208	63	169	168	192	85
	Median	56	23	46	72	71	25
	SD	598	256	604	380	453	274
	Min.	1	0	1	1	2	4
	Max.	4,567	3,430	4,753	3,088	4,011	2,994
	IQ Range	111	43	68	135	101	60
Montreal	Count	588	545	591	561	627	561
	Mean	138	28	68	143	149	52
	Median	49	14	28	56	52	22
	SD	312	36	215	278	299	134
	Min.	1	0	1	0	4	4
	Max.	3,665	274	3,640	3,298	3,167	1,751
	IQ Range	94	33	53	120	93	39
Ottawa- Gatineau	Count	404	373	410	372	421	373
	Mean	211	53	132	169	174	82
	Median	53	27	44	66	58	24
	SD	647	200	384	455	518	253
	Min.	0	1	2	1	0	4
	Max.	4,999	3,716	3,438	4,958	4,847	3,679
	IQ Range	103	44	81	102	84	65
Quebec City	Count	188	161	187	175	213	174
	Mean	334	58	444	313	582	282
	Median	76	16	40	89	85	30
	SD	745	232	1,136	586	1,135	931
	Min.	1	1	3	1	2	2
	Max.	4,823	2,865	4,874	3,960	4,927	4,834
	IQ Range	225	49	106	281	408	64

Table 2-10 (Cont'd)

City	Statistics	Tele Atlas Street -Postal Code (A-B)	Tele Atlas Street -DMTI Street (A-C)	Tele Atlas Street - DMTI MEP (A-D)	Postal Code - DMTI Street (B-C)	Postal Code - DMTI MEP (B-D)	DMTI Street - DMTI MEP (C-D)
Saint John	Count	61	59	61	61	66	61
	Mean	202	74	163	230	268	77
	Median	70	24	48	94	76	69
	SD	553	143	408	450	482	68
	Min.	3	0	3	2	7	4
	Max.	3,497	763	3,018	2,274	2,267	283
	IQ Range	102	74	112	127	114	97
Saskatoon	Count		59	67			59
	Mean		67	99			58
	Median		57	77			42
	SD		61	131			69
	Min.		4	6			4
	Max.		317	1,008			399
	IQ Range		82	81			75
St. John's	Count	58	53	57	53	59	52
	Mean	346	128	470	361	390	277
	Median	102	36	101	123	129	65
	SD	644	206	1,043	617	652	800
	Min.	2	1	6	1	3	4
	Max.	3,095	957	4,117	3,150	2,739	3,926
	IQ Range	207	114	164	303	425	107
Toronto	Count	1,394	1,327	1,395	1,340	1,426	1,340
	Mean	111	62	101	102	88	56
	Median	43	25	34	50	46	19
	SD	348	223	338	255	220	187
	Min.	0	0	1	0	1	4
	Max.	4,933	3,901	4,953	4,509	4,504	3,268
	IQ Range	62	40	64	86	60	37
Vancouver	Count	505	476	505	475	510	475
	Mean	159	78	108	125	128	47
	Median	49	15	30	49	50	20
	SD	476	320	335	396	392	126
	Min.	2	0	1	1	0	2
	Max.	3,580	2,934	2,841	3,542	3,550	1,720
	IQ Range	67	32	44	79	63	34
Victoria	Count	187	184	188	186	192	187
	Mean	112	47	124	131	126	103
	Median	49	20	36	66	67	34
	SD	255	65	415	252	364	268
	Min.	1	1	2	2	4	2
	Max.	2,601	426	4,466	2,581	4,585	2,520
	IQ Range	114	63	60	141	109	76
Winnipeg	Count	188	174	188	174	189	174
	Mean	90	47	108	102	102	73
	Median	38	33	34	54	52	19
	SD.	209	57	322	186	260	303
	Min.	1	0	2	2	4	4
	Max.	1,823	361	3,605	1,822	3,050	3,577
	IQ Range	75	43	54	79	66	29

Table 2-11. Distance differences between pairs of the geocoding methods - Nationwide

Distance	ESRI Tele Atlas Street - ESRI Postal Code		ESRI Tele Atlas Street - DMTI Street		ESRI Tele Atlas Street - DMTI MEP		ESRI Postal Code - DMTI Street		ESRI Postal Code - DMTI MEP		DMTI Street -DMTI MEP	
	(A-B)		(A-C)		(A-D)		(B-C)		(B-D)		(C-D)	
(meters)	N	CF (%)	N	CF (%)	N	CF (%)	N	CF (%)	N	CF (%)	N	CF (%)
0-100	3,546	75	4,012	89	3,895	81	3,015	67	3,536	72	3,970	87
100-200	675	89	349	97	551	92	890	86	824	88	377	95
200-300	156	92	63	98	134	95	236	92	177	92	102	97
300-400	75	94	29	99	39	96	97	94	55	93	29	98
400-500	50	95	11	99	39	96	46	95	56	94	12	98
>500	249	100	51	100	175	100	232	100	288	100	87	100
Total	4,751		4,515		4,833		4,516		4,936		4,577	

Discussion and Conclusion

The purpose of this research was to compare the geocoding completeness and positional variability for 5,086 PHC practice locations in 14 Canadian urban areas by applying a manually built geocoding service in ArcGIS and an online geocoding service provided as a built-in tool in ArcGIS. For geocoding completeness, only locations which successfully geocoded with match scores at or above 80 percent were included. For positional variation we calculated distance differences between the geocoded locations (Bow et al., 2004; Duncan, et al., 2011) instead of comparing geoocoded locations with some true location using GPS (Ward et al., 2005; Zhan, et al., 2006) or a validated baseline (Bell, et al., 2012; Cayo & Talbot, 2003; Roongpiboonsopit & Karimi, 2010a; Zandbergen, 2011), which would be time consuming and not recommended for a large number of records (Bell, et al., 2012). Before discussing the results, a few limitations need to be addressed.

First, this study focuses only on urban areas that are, or are a part of, one of 27 CMAs in Canada. It is important to interpret the results carefully while applying them to other urban areas within Canada or urban areas in other countries. Second, some urban areas in the study (e.g., Hamilton, Montreal, Ottawa) have a small number of rural addresses falling within the municipal boundaries included in the study that may result in larger positional errors (Roongpiboonsopit & Karimi, 2010b). A conservative distance (i.e. 5000 m) is considered an outlier that could limit any considerable positional error. Third, this research focused only on PHC practice sites, which are mostly located in non-residential areas (e.g., institutional and commercial areas including shopping malls). It is important to note that geocoding match rates for commercial properties are found to be lower than the rates for residential properties (Zandbergen, 2008). Finally, it is also important to note that we included all physician addresses provided by provincial sources; these may include addresses other than practice sites (e.g., physician home addresses) (McKendry et al., 2006) where match rates are higher than in commercial areas (McKendry, et al., 2006; McLafferty, Freeman, Barrett, Luo, & Shockley, 2012), and the pre-processing steps performed for data aggregation and standardization could affect the actual estimates.

When comparing the results of match rate and positional variation by integrating street and postal code methods for online and manually built geocoding services, the DMTI reference datasets perform marginally better than the ESRI Tele Altas. We found street geocoding match rates are higher in densely populated areas, which indicates that more inputs (such as merging results of geocoding methods using different reference datasets) would be required in getting maximum match rates when geocoding addresses of less densely populated urban areas. When geocoding addresses using postal code datasets, match rates are higher in all urban areas but positional accuracy, which is assessed through positional differences, has shown some variations

among urban areas. Broadly speaking, geocoding accuracy is positively "correlated" with urban population density (for population density, see Table 2-1). This is a thesis that is difficult to test statistically given the relatively small sample size (n=14), but the unique geographic landscape of Canadian urban centres is important to consider. Urban areas could be categorised into the following population density classes: under 1000 persons (least dense), 1,000 to 3,000 persons (moderately dense), and more than 3,000 persons per square kilometre (most dense). Increased city-wide accuracy in the most dense cities is likely the result of a combination of the following factors: 1) more mature street networks with well-established address ranges and a smaller proportion of unregistered street networks (a.k.a. new neighbourhood developments); 2) shorter street segments (resulting in smaller differences between range interpolated locations), 3. smaller Postal Code area reducing the potential for different locations being assigned to the same postal code in different databases; and 4) smaller proportion of urban area covered by suburban, peri-urban, ex-urban, and rural areas (Cayo & Talbot, 2003). The role of geocoding services-- whether accessed through desktop or online -- and spatial reference datasets are very important in generating geographical coordinates. This study, an empirical comparison of geocoding results, highlights that geocoding match rates could be improved by merging the results of different geocoding methods using different reference datasets.

In this study, our focus is on PHC provider practice locations that play an important role in measuring geographical healthcare accessibility, distribution of healthcare resources, and physician workforce planning: a reliable geographic location could make a big difference in mapping health care needs and services. Our results on positional variability of geocoded locations reveal that a more reliable geocoded location could be determined. More importantly, after considering the strengths, weaknesses, and positional variability of different geocoding

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methods, merging the geocoded locations could be helpful in achieving higher match rates with reliable set of geographic coordinates. More research is needed to explore the strategies for merging the results of different geocoding services for increasing match rates with reduced positional uncertainty. The most suitable strategy could be to use a hybrid geocoding approach by integrating different geocoding methods after considering their weaknesses and strengths. There are different approaches that could be applied in the course of merging results from different geocoding services. In this particular case, we first proiritized a number of geocoding services after considering their strengths, weaknesses, and positional variability. Next, from highest to lowest priority, we selected only those geocoded locations that met the selection criteria (i.e, match scores ≤ 80 percent) and repeated the same procedure with the other geocoding methods until 100 percent locations (maximum match rates) are obtained. Future research could be conducted to analyze the effectiveness of other approaches such as taking the average of different geocoding services, using merging to identify 'outlier' locations that may have inaccurate data, or using one set as a check on the others, etc. for merging results.

CHAPTER 3: SECOND MANUSCRIPT

SPATIAL ACCESSIBILITY TO HEALTH CARE SERVICES: TO IDENTIFY UNDER-SERVED AREAS IN CANADIAN URBAN SETTINGS

Authors: **Shah, T. I.**, Bell, S., & Wilson, K.

TS conceived and designed the study with SB and KW, assembled input data, analyzed and interpreted the data, and wrote the manuscript.

Chapter 3 addresses the first two objectives of this research by measuring the spatial accessibility to PHC services and identifying areas (or communities) having poor geographical access to primary health services. An index of spatial access to PHC services (i.e., accessibility score) using the Three-Step Floating Catchment Area (3SFCA) method was calculated at locally defined neighborhoods. A comparison of accessibility score to simple physician-to-population ratio was provided in this research. Further, spatial statistical techniques was applied to analyze the spatial patterns of accessibility score at neighbourhood level among 14 urban settings.

This chapter is also a continuation of my previous research work (as coauthor) on this topic. For more details on this, see Appendices B-D.

CHAPTER 3
SPATIAL ACCESSIBILITY TO HEALTH CARE SERVICES: TO IDENTIFY UNDER-
SERVED AREAS IN CANADIAN URBAN SETTINGS

Abstract

Access to primary health care (PHC) in urban settings is a pressing research and policy issue in

Canada. Most of the research on access to healthcare is focused on national and provincial levels

in Canada but there is a need to advance current understanding to local scales such as

neighbourhoods. This study measures spatial accessibility to PHC services using the Three-Step

Floating Catchment Area (3SFCA) method and identifies the areas (or neighoburhoods) having

poor geographical access to primary health services and their spatial patterns in Canadian urban

settings. Information about PHC providers used in this research was gathered from publicly

available and routinely updated sources (i.e. provincial colleges of physicians and surgeons). An

integrated geocoding approach was used to establish PHC locations. An index of spatial access

to PHC services, an access score that is comparable to simple physician-to-population ratio, was

calculated at locally defined neighborhoods using a 3km road network distance. Using

Geographic Information Systems (GIS) and spatial statistical tools, comparative analysis

performed between the urban settings highlights the variations in access to care. The results of

this study show substantial variations in geographical accessibility to PHC services both within

and across Canadian urban areas and identify the no-serviced or poorly-served neighbourhoods.

In all 14 urban areas, 23.1 and 22.2 percent of the total population (11,659,364) fall into the

following categories: less than 0.50 and 0.50-0.75 physicians-to-1000 populations respectively.

These findings enhance our understanding of the distribution of health care services and their

proximity to homes that would be helpful for policymakers, researchers, city planners, community workers, and those residents who need services.

Introduction

The term Primary Health Care (PHC) is used to refer to health care that focuses on diagnosis and treatment, illness prevention, health promotion, rehabilitation therapy, nutritional and psychological counselling, as well as referrals to specialists (Government of Alberta, 2010). In the Canadian context, primary care refers to first-point-of-contact health services between an individual and a health care practitioner such as a family physician, nurse practitioner, or pharmacist (Crooks & Andrews, 2009; Health Canada, 2006). In Canada, primary care physicians work independently or in group practices (Davis, 1999) and order diagnostic tests, write prescriptions, make referrals to specialists and allied health care providers, and admit patients to hospitals (Health Canada, 2006). Primary care is recognized as the most important form of health care for maintaining population health because it can be more easily delivered than specialty and inpatient care, and if properly distributed is most effective in preventing disease progression on a large scale (Guagliardo, 2004). That said, there are growing concerns that inequities in access to primary health care exist and that the health system is not as responsive as it could be for certain populations (Health Canada, 2001), particularly those neighbourhoods who have poor geographical access to PHC services. Health care accessibility has a direct impact on the burden of disease and is an important indicator of the performance of

any national health system (Humphreys & Smith, 2009). Access to primary care across Canada is a continuing challenge (Government of Ontario, 2012; Schuurman, et al., 2010) and is a growing issue regarding health care delivery in Canada (Allin, et al., 2010; Asanin & Wilson, 2008; Canada, 2004; Fulcher & Kaukinen, 2005; Law et al., 2005; Wilson & Rosenberg, 2002). Presently in Canada, provincial plans for health care focus on ensuring that patients are receiving care in the most appropriate setting close to their place of residence. For example, Ontario's action plan for health care is committed to reduce the number of people relying on emergency room (ER) settings for PHC by providing "timely access to the most appropriate care in the most appropriate place as close to home as possible" (Government of Ontario, 2012). Similarly, one of key benefits of the Alberta's 5 Year Health Care Plan that "more health care will be provided locally in doctors' offices, or by primary health-care teams" (Government of Alberta, 2010, p. 18) indicates the Government's intuition to address the health care at local scales.

Access is variably interpreted by policy makers, researchers, and the general public (Birch & Abelson, 1993; Penchansky & Thomas, 1981). For example, access to health care is described as a relationship between characteristics of the services delivery system and of the population at risk to the actual utilization of services and consumer satisfaction (Aday & Andersen, 1974). Penchansky & Thomas (1981), in describing access as the degree of "fit" between clients and the system identify five key dimensions of access: availability, accessibility, accommodation, affordability, and acceptability. The first two dimensions (i.e., availability and accessibility) represent the geographic dimension of access. According to Penchansky and Thomas (1981), availability describes the supply of health services in relation to the population in need, whereas accessibility describes the geographical location of health services in relation to the location of clients by considering the geographical factors (such as transportation, travel

time, distance and cost). Humphreys and Smith (2009) have extended concepts of accessibility to include the capacity of people to obtain health care at the right place and right time regardless of their location, socioeconomic factors, or cultural background. In the literature a distinction is made between potential and realized access. Potential access refers to the distribution or availability of health care services while realized access refers to the actual utilization of services (Guagliardo, 2004; Joseph & Phillips, 1984; Khan, 1992). Potential access is further divided in two components based on geographic (location and distance) and non-geographic barriers (such as socioeconomic status, income, age or gender) (Khan, 1992; Luo & Wang, 2003). In this research we focused on potential geographical (spatial) access to PHC services.

In the study of local-level access to health care, the unit of analysis is very important as the size and shape of the area chosen for investigation (e.g., county units, postal codes, census tracts, municipally-defined neighbourhoods) may produce different results depending on the chosen political (or administrative) unit of study (Nykiforuk & Flaman, 2008). In geographical studies, analytical results can be influenced by the number of areal units used (i.e., scale effect) and the choice of boundaries or level of aggregation (i.e., zonation effect) (Flowerdew, et al., 2008; Haynes, et al., 2007; Openshaw, 1983). A recent study examining the different aspects of access to health care at local scales, demonstrated that the size and shape of the selected neighbourhood matters (Bell, et al., 2013). The concept of neighbourhood has become increasingly important for the planning and analysis of urban areas (Guest & Lee, 1984). There is a need to advance current understanding of access to PHC (Wilson & Rosenberg, 2002) and its various providers (such as family physicians and general practitioners) at local scales (such as neighbourhoods).

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Many datasets are collected at the micro-scale (for example, the household) but are released and shared only after being aggregated. Census data are collected from every household but aggregated to at the smallest possible geographic scale (such as Dissemination Areas (DAs) in Canada, Statistical Area Level 1 (SA1)[12] in Australia, Census Blocks (CB) or Block Groups (BG) in USA[13] and other larger units. In the process of data aggregation at higher (or larger) spatial scales (e.g. census tracts, neighbourhoods, census sub-divisions, census districts, etc.), variability in the dataset and statistical estimation can be different. Under-served regions in this study that are conceptually similar to the medically under-served areas (MUAs) in the US (Health Resources and Services Administration, 1995; Luo, 2004) represent a neighbourhood or a group of neighbourhoods in which residents have a shortage of PHC services. This differs from the idea of medically under-served populations (MUPs) which considers the populations with economic or cultural and/or linguistic access barriers to PHC services along with physicians-to-population ratios (Health Resources and Services Administration, 1995; Luo, 2004).

However, too little attention has been paid to the potential geographical accessibility to PHC services in urban settings. Mostly this is because of apparent health care supply/availability figures in large urban settings, it is assumed there are no such underserviced or poorly served areas in urban settings. The purpose of this study is to investigate the potential geographical accessibility to PHC services across Canadian urban areas as well as its distribution within the urban fabric to determine the underserviced or poorly served neighbourhoods.

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[12] http://www.abs.gov.au/ausstats/abs@.nsf/0/7CAFD05E79EB6F81CA257801000C64CD
[13] http://www.census.gov/geo/reference/garm.html

Methods

In this study, we measure spatial accessibility to PHC services in Canadian urban settings using the Three-Step Floating Catchment Area (3SFCA) method to examine intra-urban variations in access to care. We also identify neighbourhoods with poor geographical access to PHC services by analyzing their spatial distribution patterns of accessibility score. Note that primary health care in Canada is provided by a pool of professionals such as doctors, nurses, pharmacists, dieticians, rehabilitation therapists, social workers, etc.(Government of Alberta, 2010; Health Canada, 2006); however, this study includes the family doctors (Family Physicians, General Practitioners, or Non-Specialists) only. The research is focused on 14 urban areas across Canada (According to the Statistics Canada, any area with a minimum population of 1,000 people and a population density of 400 or more people per square kilometer is considered an urban area[14], which together represent all provinces with Census Metropolitan Areas (CMAs)[15], as follows: Victoria and Vancouver, British Columbia; Calgary and Edmonton, Alberta; Saskatoon, Saskatchewan; Winnipeg, Manitoba; Hamilton and Toronto, Ontario; Ottawa–Gatineau, Ontario and Québec; Montréal and Québec City, Québec; Halifax, Nova Scotia; Saint John, New Brunswick; and St. John's, Newfoundland (see study area map given in the Figure 3-1).These urban areas have been selected for comparative purposes after considering their distinct characteristics. Each urban area consists of at least one Census subdivision[16] (or Municipality, in more common terms) for which locally relevant neighbourhoods exist (for details, see Table 3-1). There is a range of ways in which neighbourhoods are defined that includes delineation using

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[14] http://www.statcan.gc.ca/subjects-sujets/standard-norme/sgc-cgt/notice-avis/sgc-cgt-06-eng.htm
[15] The census metropolitan area (CMA) as defined by Statistics Canada in the 2011 census is one or more adjacent census subdivisions (or municipalities) gathered around a core (of population) having a total population of at least 100, 000 and out of which 50,000 or more must be located with the core area.
[16] Census subdivision (CSD) as defined by Statistics Canada in the 2011 census is the general term for municipalities (as defined by provincial/territorial legislation) or areas treated as municipal equivalents for statistical purposes.

physical features, by following administrative boundaries, consisting of census areal units, etc., and some definitions respect residents' perceptions about neighbourhoods. In recent years, there has been an increasing amount of literature on use of meaningful units of analysis in geographical research (Bissonnette, et al., 2012; Flowerdew, et al., 2008; Ross, et al., 2004; Santos, Chor, & Werneck, 2010). In urban settings, locally developed or relevant (or natural) neighbourhood units are found more meaningful units of analysis than neighbourhoods defined by data availability (e.g., dissemination areas, census tracts, etc.) (Bissonnette, et al., 2012; Ross, et al., 2004). In this research, municipal defined neighbourhoods are used. A Canadian company, DMTI Spatial, collected neighbourhood information that includes paper maps, computer aided drawing (CAD) files, etc. from different municipalities and compiled them into a single GIS layer (DMTI Spatial, 2011b). This neighbourhood layer is used to calculate physician-to-population ratio (or accessibility score) at a local scale. The conceptual definition of a local neighbourhood as given by DMTI is as follows (DMTI Spatial, 2010, p. 5):

> "A geographically localized area within a larger city, town or suburb. Neighbourhoods are often social communities with considerable face-to-face interaction among members. *Neighbourhoods* can be used to refer to the small group of houses with similar housing types and market values. *Neighbourhood*s can also describe an area surrounding a local institution patronized by residents, such as a church, school, or social agency. The concept of neighborhood includes both geographic (place-oriented) and social (people-oriented) components."

Figure 3-1. Location of Urban areas used in this study

Table 3-1. Study Areas: Information about PHC providers, data sources and 2011 Census data for 14 Urban Areas

Urban Area	2011 Census Subdivisions		Primary Health Care Services		Data sources
	n	Population	Practice Sites	Physicians	
Calgary	1	1,096,184	466	1,070	(CPSA, 2010)
Edmonton	2	873,157	347	839	(CPSA, 2010)
Halifax	1	390,091	168	454	(CPSNS, 2011)
Hamilton	2	656,574	264	552	(CPSO (College of Physicians and Surgeons of Ontario), 2011)
Montreal	16	1,886,481	635	1,542	(CMQ (Collège des médecins du Québec), 2010)
Ottawa-Gatineau	2	1,148,740	448	1,196	(CMQ (Collège des médecins du Québec), 2010; CPSO (College of Physicians and Surgeons of Ontario), 2011)
Québec City	4	672,136	217	751	(CMQ (Collège des médecins du Québec), 2010)
Saint John	2	82,010	60	87	(CPSNB (College of Physicians and Surgeons of New Brunswick), 2010)
Saskatoon	1	221,849	68	234	(CPSS (College of Physicians and Surgeons of Saskatchewan), 2010)
St. John's	5	180,396	62	196	(CPSNL(College of Physicians and Surgeons of Newfoundland and Labrador), 2011)
Toronto	1	2,615,060	1435	2,579	(CPSO (College of Physicians and Surgeons of Ontario), 2011)
Vancouver	3	892,696	516	1,067	(CPSBC(College of Physicians and Surgeons of British Columbia), 2011)
Victoria	9	280,373	192	428	(CPSBC(College of Physicians and Surgeons of British Columbia), 2011)
Winnipeg	1	663,617	188	528	(CPSM (College of Physicians and Surgeons of Manitoba), 2010)
Total	50	11,659,364	5,066	11,523	

Note: n represents the number of municipalities in an urban area selected for this research.

Data

Like other GIS based methods measuring geographic accessibility to health care, the 3SFCA method requires the location of PHC services (this definition does not include mobile services such as health buses or nurse practitioners or less distributed services such as emergency rooms) and population information associated with geographic areas (Bell, et al., 2013; Luo, 2004; Luo & Wang, 2003; Paez, Mercado, Farber, Morency, & Roorda, 2010; Schuurman, et al., 2010). In the first stage of data collection, information about physician's practice sites were derived from individual profiles collected from the Provincial Colleges of Physicians and Surgeons. Information about data sources and acquisition date is given in Table 3-1. In this study, only those physicians specified as Family Doctors/ Physicians, General Practitioners or Non-specialists and those who have their primary practice sites within the municipal boundaries of the study areas examined were considered. It is important to note that the database (Physician directory) does not provide information on the working hours of physicians (e.g, full-time, part-time, or if they provide after hours services), the size of patient practices, or whether or not physicians are accepting new patients into their practice. While these are all important factors that shape accessibility, they fall beyond the scope of the study.

In total, there were 5,066 practice sites in the 14 urban areas associated with a total of 11,523 physicians providing PHC services (for urban area details, see Table 3-1). The geographic coordinates (latitude and longitude) for PHC practice sites were generated by applying an integrated geocoding process. Geocoding results from manually built and online geocoding services (using different reference datsets) were combined for maximum match rate (i.e., 100 percent) with reduced positional uncertainty (for details on the geocoding process used, see article by Shah, Bell, and Kathi (2014)). Population data was taken from the 2011 Census of

Canada. In Canada, Census data is disseminated at a wide range of geographic areas. Dissemination Area (DA), the smallest geographic area at which complete census data is released, was used in this study. The geographic coordinates (latitude and longitude) for DAs are provided by Statistics Canada (as a part of the GeoSuite product[17]). The following digital layers used in this research were obtained through the University of Saskatchewan, Saskatoon: a municipality defined neighbourhood layer (DMTI Spatial, 2011b) used for analysis; CanMAP Streetfiles (DMTI Spatial, 2011a) used for the street geocoding process and estimation of catchment areas; DMTI Platinum postal code (DMTI Spatial, 2011c) used for the geocoding process.

Methodology: Measuring spatial access to PHC services

In this research we focused on potential geographical access to PHC services. Based on supply and demand data, there are two different approaches for measuring access to health care. As discussed by Joseph and Phillips, (1984), the first approach involves measuring the regional distribution of supply versus demand, or simply measuring regional availability with the assumption that regional boundaries are impermeable. This approach is suitable for those studies considering large regions as the unit of analysis, for example, census divisions (Pong & Pitblado, 2005), health areas (Olatunde, 2007; Thommasen & Thommasen, 2001), and utilization-based service areas (Shipman, et al., 2010). The second approach involves more complex calculations of access that use spatial interaction processes (e.g., distance decay) in the manipulation of supply and demand data at local scales (Guagliardo, 2004; Joseph & Phillips, 1984; Luo &

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[17] GeoSuite, 2011 Census. Statistics Canada Catalogue no. 92-150-X.

Wang, 2003; Schuurman, et al., 2010; Wang, 2012). Gravity models and kernel density estimations are the most common calculations in this second approach. The Two Step Floating Catchment Area method is derived from earlier gravity model approaches (Luo, 2004; Luo & Wang, 2003; Radke & Mu, 2000; Wang & Luo, 2005) and was developed over the last ten years to measure physician to provider ratios in study areas (see Bagheri, Benwell, & Holt, 2005; Luo & Wang, 2003). In contrast to simple counts of physicians and population within a neighbourhood, the 2SFCA takes into account the fact that individuals in one neighbourhood may seek care in other neighbourhoods. In doing so, it provides more accurate measures of potential accessibility. In the first step, the 2SFCA places a buffer, or catchment around a point of health care supply, and calculates a provider-to-population ratio within it. In the second step, it then places a second buffer around a point of population demand, and sums the ratios from all provider points within that second buffer. The two-step buffering accommodates for health care being sought across areal unit borders (i.e., neighbourhoods) (For more details, see Fahui, 2006, pp. 80-95). However, one limitation of the 2SFCA is its reliance on a single buffer size assuming access to be uniform within that buffer (Luo & Qi, 2009), which could be accommodated by deriving variable catchment size where target population or catchment area is already known (Luo & Whippo, 2012). This can be problematic when the units of analysis vary in size and can result in under and overestimation of access across units (McGrail & Humphreys, 2009). There are several cases in which this may occur. To avoid the methodological inaccuracies involved when examining variably sized neighbourhoods, we utilize the 3FSCA method described in detail by Bell, Wilson, Bissonette, & Shah (2013) and Bissonnette, Wilson, Bell, & Shah (2012). In short, the first and second steps of the method are consistent with the 2SFCA analysis; however, as a point of population demand, we introduce a smaller census unit known as a

dissemination area (DA), rather than using neighbourhood centroids. In an additional third step, an access ratio at the neighbourhood level is calculated by averaging the 2SFCA access ratios for all DAs falling within a neighbourhood. The third step results in a neighbourhood-level access ratio that is independent of neighbourhood size. This reduces methodological inaccuracies because the DAs used are smaller and more uniformly sized than neighbourhoods.

In the case of this research 3km network buffers were selected for analysis. There is no consensus in the literature on buffer distances for access to health care and the existing body of literature uses distances ranging between 1.5 and 35 miles (2.4 and 56.3 kilometers) (Luo, 2004). This research employs a more moderate distance of 3km (in the first two steps of the method used), based on the premise that local (i.e., neighbourhood) access to primary care is important if not universally put into practice during the family doctor selection process (see Goodman et al., 2003). However, it is important to acknowledge that these measures are limited to physical distance and cannot account for the amount of time it takes to travel set distances, a result of both physical and transportation barriers.

In the first stage of analysis, the 3SFCA method was applied to calculate potential geographic (spatial) accessibility to PHC services in the 14 study areas. For this process, the following input datasets were used: a geocoded layer of PHC practice sites that represents PHC supply ; the 2011 DA locations and associated population that represents demand for health care services (Statistics Canada, 2011); and a digital neighbourhood (geographic) boundary file as a unit of analysis (DMTI Spatial, 2011b). Catchment areas around all locations of PHC services and census DA points required for the 3SFCA calculations were created using the service area function in Network Analyst, an extension of ArcGIS 10 software, by setting 3km road distance.

Analyzing geographical patterns

Initial analysis involved an assessment of clustering in the distributions of PHC accessibility. The data used to assess clustering are the 3SFCA access scores presented as a single value (i.e., physicians-to-population ratio) for each neighbourhood. Anselin's local indicator of spatial association (LISA), a local form of Moran's I, was applied for statistical confirmation and identification of clusters in urban fabric as well (Anselin, 1995; Anselin, Syabri, & Kho, 2006). The LISA measures whether the 3SFCA accessibility score of a neighbourhood is closer to the values of its neighbours or to the average of the urban area (see Anselin, 1995). In the cluster detection process, the choice of a weight matrix is very important because it establishes the spatial relationship of the areal units (i.e., 'neighbourhoods' in this case). In this study the univariate LISA tool provided in GeoDa software (Anselin, et al., 2006) was applied to each urban area separately and the following parameters were selected to compute global and local Moran's I statistics: Queen's case contiguity (1st order) that considers all possible connectivity between areas as a weight matrix, a larger number of permutations (i.e., 999) to assess the sensitivity of results, and the significance filter set to .05. By applying the univariate LISA function, GeoDa generated four different types of result graphs and maps: a significance map, a cluster map, a box plot and a Moran scatter plot. For this purpose, GeoDa offered a set of three output variables for each unit of analysis: 1. the value for local Moran statistics or LISA indices; 2. an indicator for the type of clusters for significant locations only; and 3. the p-values from the permutation routine.

Results

The results of physician-to-population ratios for the 14 CMAs estimated using the 3SFCA method are presented in Table 3-2 (see also Figure 3-2). The column labeled 'Simple Ratio' shows the simple calculations or physician to population ratios at the city scale (i.e., [PHC physicians in a City / 2011 Census population of that City]*1000) while the column labeled 'Mean Neighbourhood Simple Ratio' is initially measured at the neighbourhood level using the same formula. The column labeled 'Mean 3SFCA Score' shows the 3SFCA calculations. The basic difference between these ratios are that the 'Mean 3SFCA Score' and 'Mean Neighbourhood Simple Ratio' were calculated at the neighbourhood level and then averaged out by urban areas, while the 'Simple Ratio' was calculated only at the City scale using the total number of physicians and the total population in the respective urban area. It is important to demonstrate the difference between these methods first. As discussed in the Methods section above, a simple ratio method is suitable for those studies considering large regions as the unit of analysis including provinces, Census divisions, census subdivisions/municipalities, and census metropolitan areas. There are two issues associated with the simple ratio method (i.e., no values are assigned to a large number of units of analysis, and some unit of analysis have very high values) when one applies this process at a local scale to neighbourhoods, census tracts, wards, etc. (see Table 3-3). To illustrate this, both methods (i.e., simple ratio, and 3SFCA) are applied to the following cities: Toronto, Montreal, and Vancouver (see Figure 3-3) where a large number of analysis units are without physician-to-population ratios (i.e., 82, 25, 25 neighbourhoods in Toronto, Montreal, and Vancouver respectively). This is one of the typical problems in using the simple ratio method at local level scales. Secondly, it provides very high ratio values (for example, 32.9, 9.2, 6.4 physicians per 1000 population in the case of Toronto, Montreal, and

Vancouver respectively) and in total, there are eight urban areas having maximum ratio values of more than 10 physicians per 1000 people. In contrast, the 3FSCA method handles these aspects of ratios very well by calculating scores for those neighbourhoods that have no PHC services and by controlling the extreme values as shown in this example.

Table 3-2. Summary of physician-to-populations ratios by urban areas

Urban Area	PHC Services		Population	Physicians per 1000 people		
	Practice Sites	Physicians	2011 Census	Simple Ratio^	Mean Neighbourhood Simple Ratio^^	Mean 3SFCA Score^^^
Calgary, AB	466	1,070	1,096,184	0.98	1.33	1.14
Edmonton, AB	347	839	873,157	0.96	1.18*	0.89
Halifax, NS	168	454	390,091	1.16	1.22	1.20
Hamilton, ON	264	552	656,574	0.84	0.74	0.80
Montreal, QC	635	1,542	1,886,481	0.82	0.78	0.80
Ottawa-Gatineau, ON & QC	448	1,196	1,148,740	1.04	0.98	1.07
Québec City, QC	217	751	672,136	1.12	1.12	1.15
Saint John, NB	60	87	82,010	1.06	0.86	0.85
Saskatoon, SK	68	234	221,849	1.05	1.46	1.01
St. John's, NL	62	196	180,396	1.09	1.46	1.32
Toronto, ON	1,435	2,579	2,615,060	0.99	1.28	0.98
Vancouver, BC	516	1,068	892,696	1.20	0.93	0.91
Victoria, BC	192	427	280,373	1.52	1.68	1.45
Winnipeg, MB	188	528	663,617	0.80	0.85	0.80
Grand Total	5,066	11,523	11,659,364	0.99	1.14	0.99

^Estimated using the following Simple ratio formula: PHC physicians in a city / 2011 Census population of the city] X 1000*; ^^Estimated using the same simple ratio at neighbourhood level data; ^^^ Estimated using the 3SFCA method; * a very high value '400' is not included.
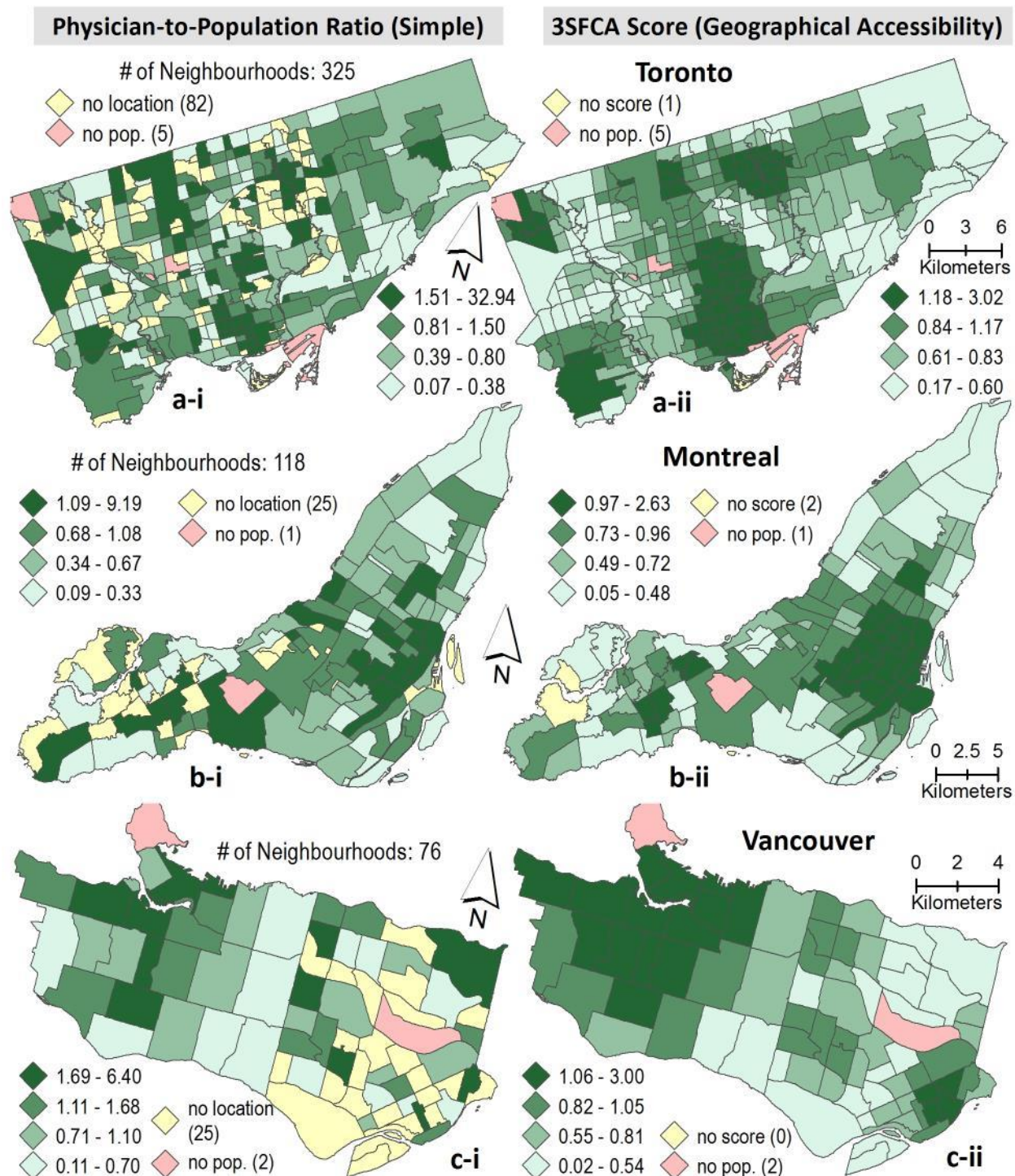
Figure 3-2. A comparison of physician-to-population ratio between simple ratio calculated using ([Physicians in an area/population of the area]*1000) (in left column), and b) three- step floating catchment areas (3SFCA) method at the neighbourhood level (in right column) in three Canadian cities (a. Toronto, b. Montreal, and c. Vancouver).
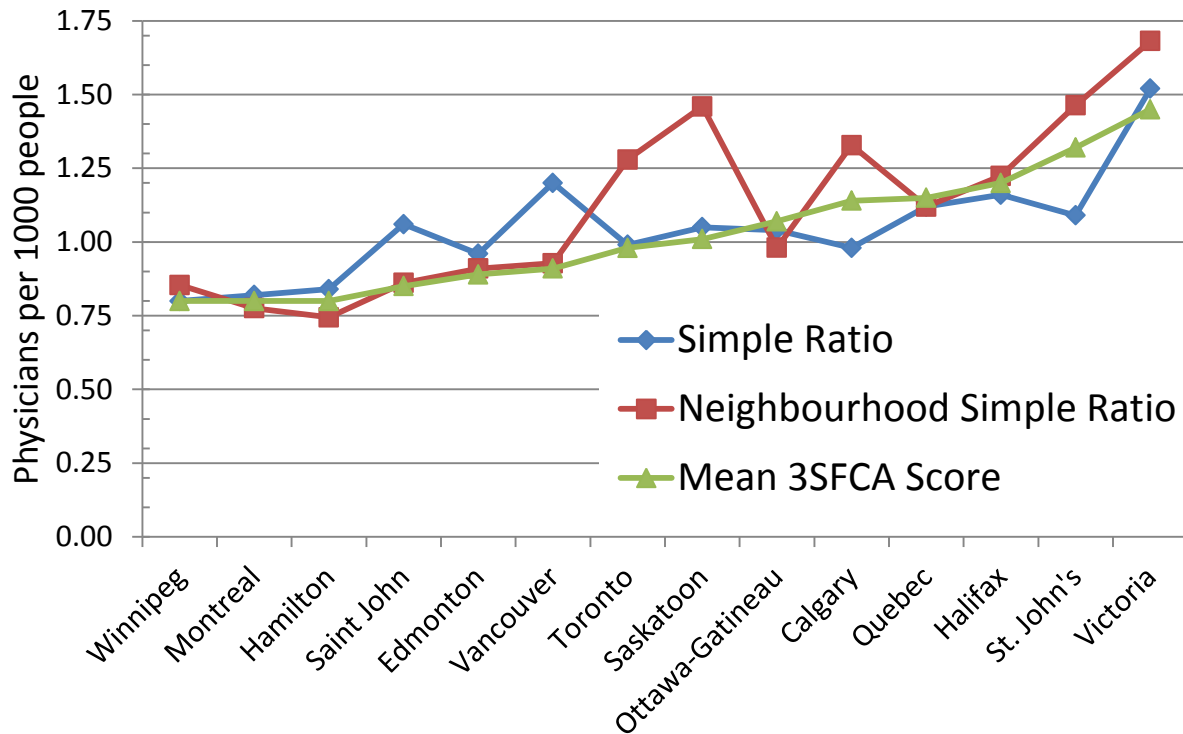
Figure 3-3. A comparison of population to physician ratios: simple ratio estimated at city level; City mean of simple ratio estimated at neighbourhood level; 3SFCA mean accessibility scores estimated at neighbourhood level.

The three methods, Simple Ratio, Neighbourhood Simple Ratio, and 3SFCA, produce similar City level access scores which are found to be highly correlated with each other (Pearson correlation coefficient, r = 0.782, P = 0.001). However, some variations are observed at City level (i.e., urban areas) physician-to-population ratios where the 3SFCA method over (such as St. John's and Calgary) and under (such as Vancouver and Saint John), estimates access to PHC services. The results do show variations across the 14 CMA study sites. For example, Winnipeg appears to have the lowest levels of access to PHC physicians of all 14 urban areas while Victoria has the highest in both methods (Simple Ratio and 3SFCA); the differences are 0.74 and 0.65 respectively.

The box and whisker plots (see Figure 3-4) show the median, range, and interquartile range of the accessibility scores (3SFCA) between urban areas. To analyze the distribution of geographical accessibility to PHC services between the urban areas, we used the Kruskal-Wallis one-way analysis of variance by ranks to test whether there are variations between the urban areas on 3SFCA accessibility scores. The results show variations across the 14 urban areas (H = 77.865, 13 d.f., p 0.001). Variations in geographical accessibility to PHC services between urban areas within the same province are evident (i.e., Victoria and Vancouver, British Columbia; and Toronto and Hamilton, Ontario).

The geographic distributions of 3SFCA accessibility scores in the 14 urban areas are shown in Figure 3-4. The accessibility scores are categorized into six manually defined classes: less than 0.50; 0.50-0.75; 0.76-1.00; 1.01-1.25; 1.26-1.50; 1.51 and above. The number of neighbourhoods and population proportions (in both counts and percentages) that fall into these six categories are given in Table 3-4. For all measures, higher numbers represent better access to PHC services. The first two classes, labeled as < 0.50 and 0.50-0.75, represent the neighbourhoods with the lowest accessibility to PHC services. With respect to the spatial distribution of access within the CMAs, the results show that the highest access neighbourhoods tend to be clustered in the central or downtown area of all CMAs with accessibility levels decreasing in the neighbourhoods immediately surrounding the downtown area, and further decreasing at the urban periphery. It is important to mention that in this study multiple downtown or core areas are present in some CMAs (for example; Hamilton, Vancouver, Edmonton, etc.). Overall, 23.1 and 22.2 percent of the total population (i.e. 2,697,493 and 2,589,539 out of 11,659,364) fall into the first (< 0.50) and second (0.50-0.75) categories respectively. The largest population proportions (63.1 percent of 663,617 population and 54.8 percent of 1,096,184

population) in categories less than 0.50 and 0.50-0.75 are found in Winnipeg and Calgary respectively.

The association between an access score (i.e., 3SFCA) at a particular neighbourhood and access scores for its neighbours is measured using the LISA statistics. The LISA cluster maps for all 14 CMAs with Global Moran's I results, providing initial evidence of clustering of accessibility to PHC services, are shown in Figure 3-5. The Moran's I values vary from a minimum of 0.432 for Halifax to a maximum value of 0.773 for St. John's. Spatial clusters based on positive spatial association are labeled as 'High-high' and 'Low-low' referring to neighbourhoods that have high (or low) spatial accessibility scores and are surrounded by high (or low) values. Whereas spatial clusters (also called spatial outliers) based on negative spatial association are indicated as 'High-low' and 'Low-high' refer to neighbourhoods that have high (or low) accessibility that are surrounded by low (or high) accessibility values. The results show that the neighbourhoods with high 3SFCA values are located in the downtown core areas of CMAs and underserved neighbourhoods (i.e., low 3SFCA values) in most urban areas are located along borders of the municipalities. Table 3-5 shows the results of spatial clusters of the 3SFCA accessibility score and the population proportion (in percentage) for each category of accessibility scores (there are in total six categories: less than 0.50; 0.50-0.75; 0.76-1.00; 1.01-1.25; 1.26-1.50; 1.51 and above, as given in Figure 3-4 and Table 3-4) are further divided by LISA clusters. For example, 23.1 percent of the total population in all urban areas that fall in the lowest accessibility category (i.e., accessibility score less than 0.50) is further divided into three groups: 40.4 percent of this 23.1 percent population fall in the Low-low cluster, 0.1 percent in the low-high and 59.5 percent in non-cluster neighbourhoods as shown in Table 3-4. Overall,

40.4, 20.4, and 2.7 percent out of the total percent of the first three categories (first (< 0.50),

second (0.50-0.75), and third (0.75-1) respectively) fall in the low-low cluster type.
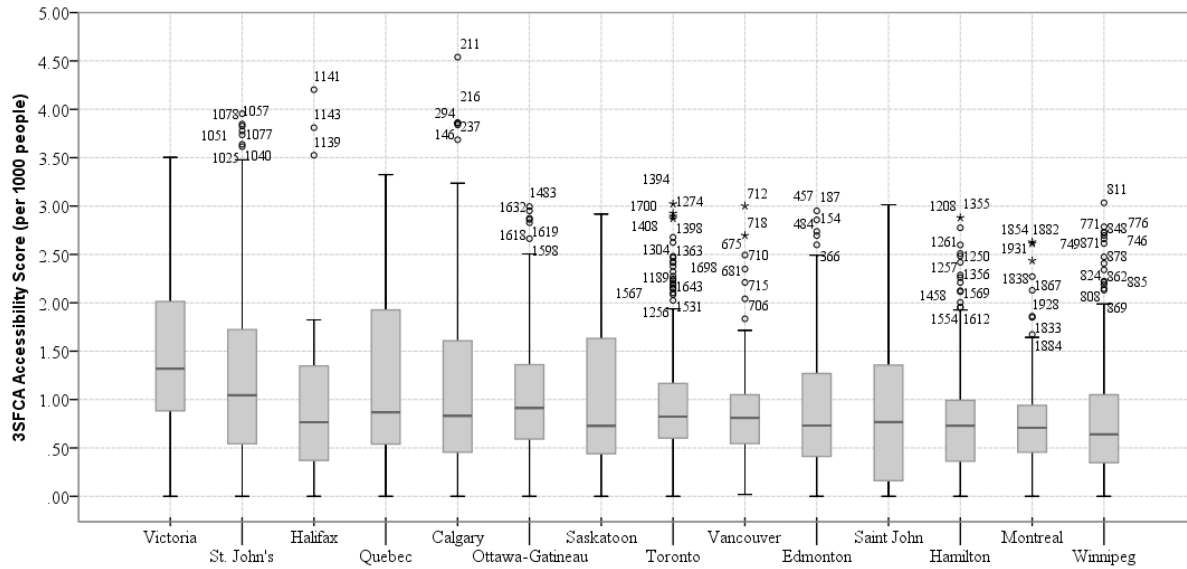
Figure 3-4. Box and whisker plots: a comparison of accessibility scores (3SFCA) by Urban Areas

Table 3-3. Number of neighbourhoods by physician-to-population ratios estimated by the simple ratio method ([Physicians in a neighbourhood/population of that neighbourhood]*1000), and three steps floating catchment areas (3SFCA) method at the neighbourhood level.

Urban Area	Number of Neighbourhoods		# of neighbourhoods by Simple ratio			# of neighbourhoods by 3SFCA score		
	Total	No data	with ratio	no ratio	sub-total	with ratio	no ratio	sub-total
Calgary	223	22	143	58	201	198	3	201
Edmonton	351	80	129	142	271	261	10	271
Halifax	23		22	1	23	22	1	23
Hamilton	208	32	89	87	176	169	7	176
Montreal	118	1	92	25	117	115	2	117
Saint John	33	2	13	18	31	24	7	31
Saskatoon	82	12	33	37	70	68	2	70
St. John's	145	3	34	108	142	131	11	142
Toronto	325	5	238	82	320	319	1	320
Vancouver	76	2	49	25	74	74		74
Victoria	67	6	42	19	61	57	4	61
Winnipeg	230	39	80	111	191	180	11	191
Ottawa-Gatineau	93		73	20	93	92	1	93
Québec City	50	1	45	4	49	46	3	49
Total	2,024	205	1,082	737	1,819	1,756	63	1,819
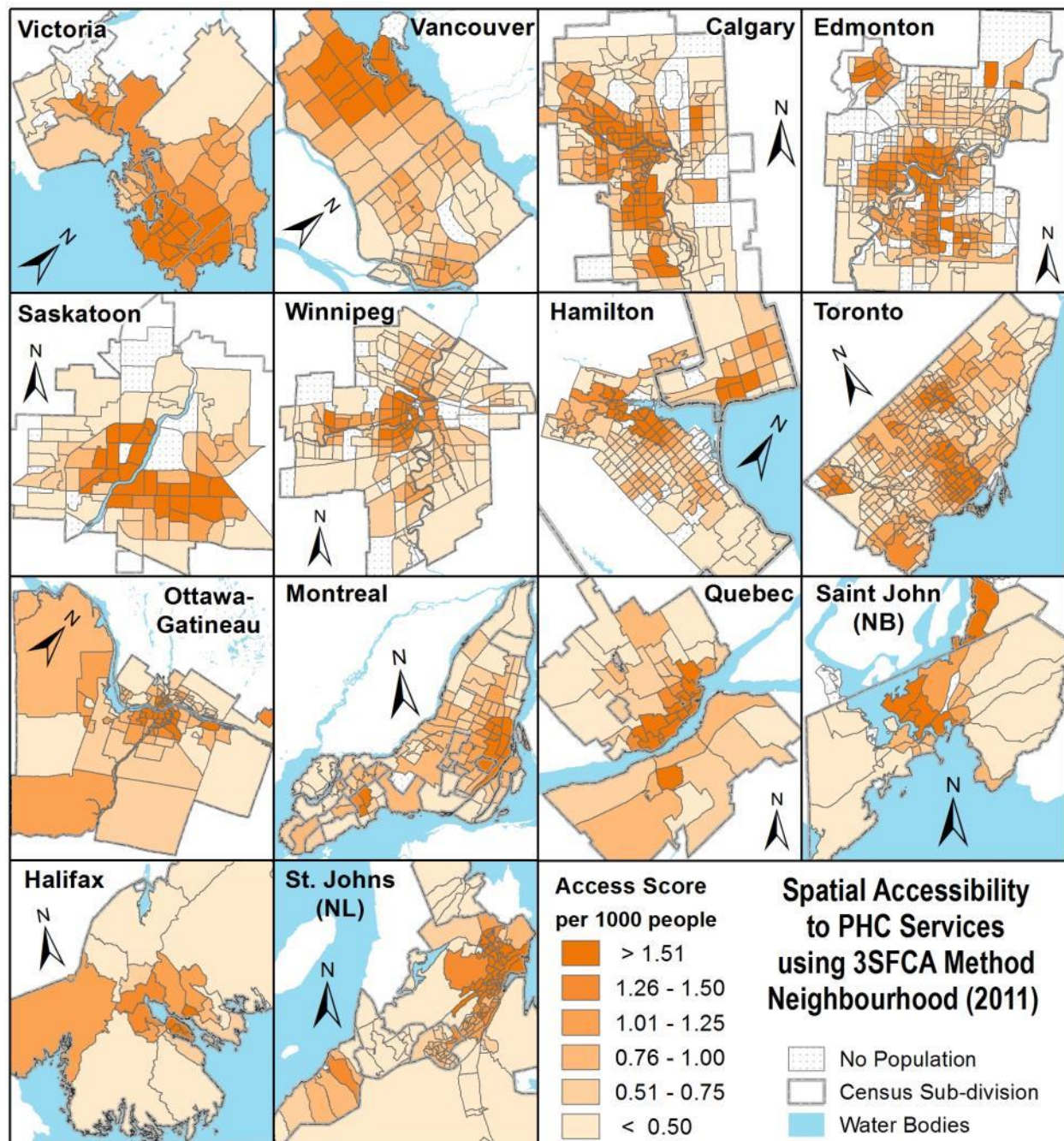
Figure 3-5. Spatial accessibility to PHC services by urban areas at the neighbourhood level estimated using the three steps floating catchment areas method (2011 DA Population, 3km road network buffer distance).

Table 3-4. Spatial Accessibility to PHC services by urban areas: distributions of population (count and percentage) and number of neighbourhood units by access score (physicians per 1000 people)

Urban Areas	Variables / Access Score	<0.50	0.50-0.75	0.76-1.00	1.01-1.25	1.26-1.50	>1.50	Total
Calgary	Population	423,921	176,322	108,010	46,531	113,409	227,991	1,096,184
	(%) Unit 'n'	(38.7) 61	(16.1) 32	(9.9) 20	(4.2) 13	(10.3) 19	(20.8) 56	(100) 201
Edmonton	Population	260,884	158,904	92,159	121,607	67,854	171,749	873,157
	(%) Unit 'n'	(29.9) 85	(18.2) 52	(10.6) 32	(13.9) 31	(7.8) 25	(19.7) 46	(100) 271
Halifax	Population	116,821	56,276	33,313	69,786	36,240	77,655	390,091
	(%) Unit 'n'	(29.9) 7	(14.4) 3	(8.5) 2	(17.9) 4	(9.3) 2	(19.9) 5	(100) 23
Hamilton	Population	205,968	129,998	137,822	49,462	24,532	108,792	656,574
	(%) Unit 'n'	(31.4) 61	(19.8) 31	(21.0) 42	(7.5) 17	(3.7) 3	(16.6) 22	(100) 176
Montreal	Population	556,145	423,412	514,545	150,133	28,107	214,139	1,886,481
	(%) Unit 'n'	(29.5) 33	(22.4) 28	(27.3) 33	(8.0) 8	(1.5) 2	(11.4) 13	(100) 117
Ottawa-Gatineau	Population	188,272	254,373	277,691	121,686	88,001	218,717	1,148,740
	(%) Unit 'n'	(16.4) 16	(22.1) 20	(24.2) 19	(10.6) 11	(7.7) 7	(19.0) 20	(100) 93
Quebec	Population	127,888	176,723	133,350	15,424	43,650	175,101	672,136
	(%) Unit 'n'	(19.0) 11	(26.3) 11	(19.8) 8	(2.3) 1	(6.5) 3	(26.1) 15	(100) 49
Saint John	Population	25,740	5,190	14,085	3,187		33,808	82,010
	(%) Unit 'n'	(31.4) 13	(6.3) 2	(17.2) 6	(3.9) 2	(0.0) 0	(41.2) 8	(100) 31
Saskatoon	Population	64,833	51,083	20,411	12,892	7,635	64,995	221,849
	(%) Unit 'n'	(29.2) 23	(23.0) 14	(9.2) 7	(5.8) 3	(3.4) 2	(29.3) 21	(100) 70
St. John's	Population	58,829	16,954	26,231	14,522	18,386	45,474	180,396
	(%) Unit 'n'	(32.6) 32	(9.4) 12	(14.5) 23	(8.1) 15	(10.2) 13	(25.2) 47	(100) 142
Toronto	Population	330,316	723,520	690,191	324,156	156,016	390,861	2,615,060
	(%) Unit 'n'	(12.6) 48	(27.7) 85	(26.4) 78	(12.4) 36	(6.0) 22	(14.9) 51	(100) 320
Vancouver	Population	65,637	221,123	230,887	96,108	17,354	261,587	892,696
	(%) Unit 'n'	(7.4) 14	(24.8) 19	(25.9) 18	(10.8) 10	(1.9) 2	(29.3) 11	(100) 74
Victoria	Population	17,968	31,313	32,840	38,478	49,409	110,365	280,373
	(%) Unit 'n'	(6.4) 7	(11.2) 6	(11.7) 7	(13.7) 9	(17.6) 9	(39.4) 23	(100) 61
Winnipeg	Population	254,271	164,348	73,400	39,805	42,085	89,708	663,617
	(%) Unit 'n'	(38.3) 70	(24.8) 43	(11.1) 26	(6.0) 16	(6.3) 12	(13.5) 24	(100) 191
Total Population		2,697,493	2,589,539	2,384,935	1,103,777	692,678	2,190,942	11,659,364
Proportion (%) Unit 'n'		(23.1) 481	(22.2) 358	(20.5) 321	(9.5) 176	(5.9) 121	(18.8) 362	(100) 1819
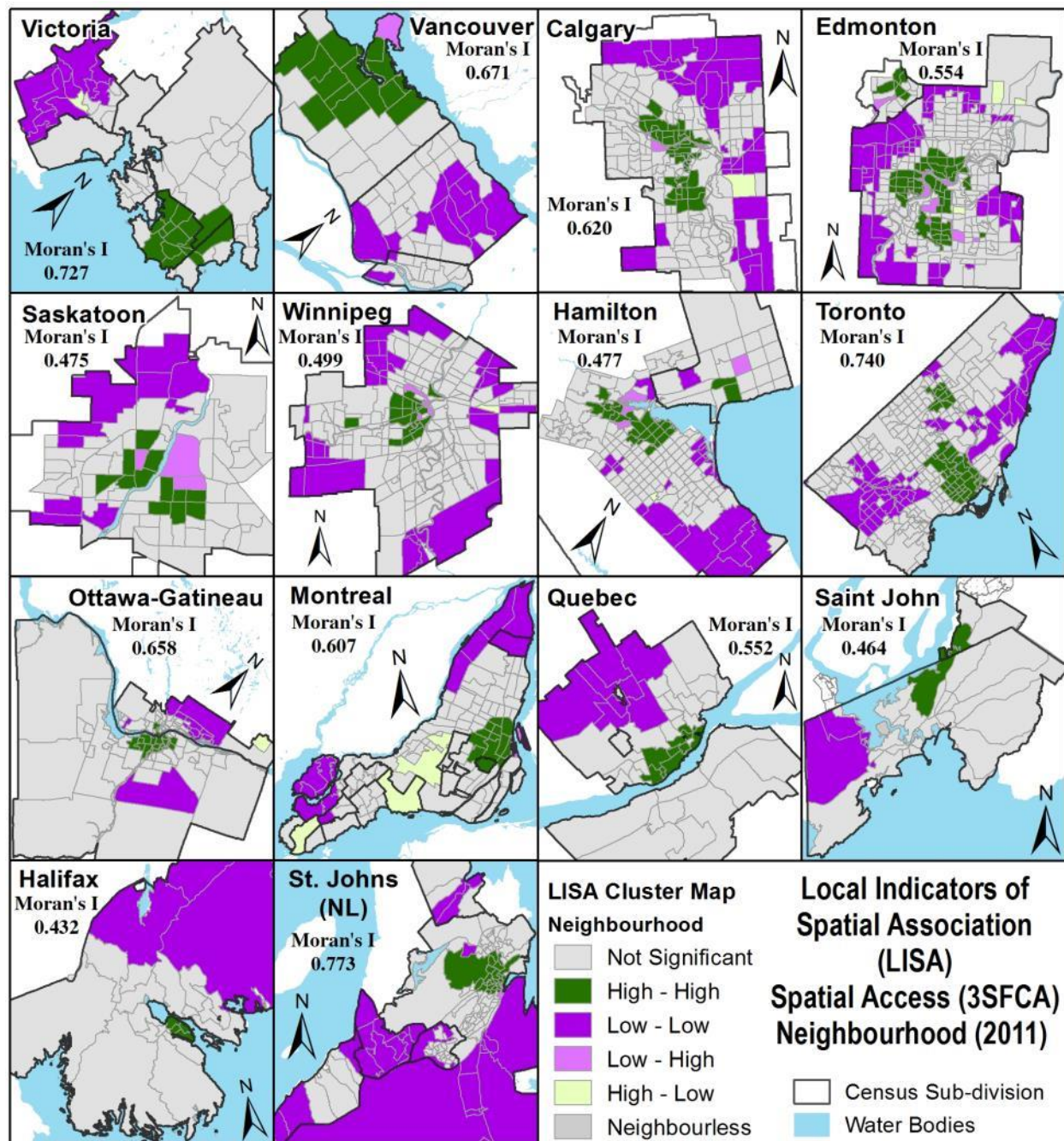
Figure 3-6. LISA cluster map of spatial accessibility to PHC services (physicians to population ratio) by urban areas. Global Moran's I of urban areas as given are found statistically significant (pseudo significant = 0.05).

Table 3-5. Proportion (%) of population in urban areas by group of accessibility score and LISA clusters

Access	Cluster	Calgary	Edmonton	Halifax	Hamilton	Montreal	Ottawa-Gatineau	Quebec	Saint John	Saskatoon	St. John's	Toronto	Vancouver	Victoria	Winnipeg	Total
	LL	46.9	28.6	45.2	22.3	36.4	16.9	38.7	10.1	37.4	79.6	75.6	65.5	61.8	22.5	40.4
<0.5	LH	0.0	0.6	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	NS	53.1	70.9	54.8	77.7	63.4	83.1	61.3	89.9	62.6	20.4	24.4	34.5	38.2	77.5	59.5
<0.5		38.7	29.9	29.9	31.4	29.5	16.4	19.0	31.4	29.2	32.6	12.6	7.4	6.4	38.3	23.1
	HH	0.0	0.0	0.0	0.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	LL	14.0	11.8	0.0	0.4	8.8	22.8	25.7	0.0	0.0	48.8	43.0	9.5	0.0	2.5	20.4
0.5-0.75	LH	0.0	0.0	0.0	5.7	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.3
	NS	86.0	88.2	100	93.2	91.2	77.2	74.3	100	100	51.2	57.0	90.5	100	97.5	79.3
0.5-0.75		16.1	18.2	14.4	19.8	22.4	22.1	26.3	6.3	23.0	9.4	27.7	24.8	11.2	24.8	22.2
	HH	0.0	5.3	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	8.6	0.0	0.0	1.3
	LL	2.1	0.0	0.0	0.0	0.0	3.5	21.0	0.0	0.0	2.6	2.8	0.0	11.9	0.0	2.7
0.75-1	LH	2.9	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.8	0.0	0.0	0.0	0.0	0.0	0.2
	HL	0.0	0.0	0.0	0.0	13.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	5.9	3.2
	NS	95.0	94.7	100	96.2	86.2	96.5	79.0	100	96.2	97.4	97.2	91.4	88.1	94.1	92.7
0.75-1		9.9	10.6	8.5	21.0	27.3	24.2	19.8	17.2	9.2	14.5	26.4	25.9	11.7	11.1	20.5
	HH	0.0	27.8	0.0	18.0	29.2	6.9	0.0	31.3	0.0	0.0	1.5	28.4	0.0	7.0	11.9
	LL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	4.9	0.0	0.2
1-1.25	LH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	3.6	0.0	0.0	0.0	0.0	0.0
	HL	1.2	0.0	0.0	1.5	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.1
	NS	98.8	72.2	100	80.5	70.8	93.1	100	68.7	100	96.4	98.5	71.6	95.1	93.0	87.8
1-1.25		4.2	13.9	17.9	7.5	8.0	10.6	2.3	3.9	5.8	8.1	12.4	10.8	13.7	6.0	9.5
	HH	7.3	47.5	0.0	31.5	85.3	30.4	0.0		100	13.1	28.6	78.1	0.0	58.9	27.7
1.25-1.5	HL	0.0	0.0	0.0	0.0	0.0	13.7	0.0		0.0	0.0	0.0	0.0	0.0	0.0	1.7
	NS	92.7	52.5	100	68.5	14.7	55.9	100		0.0	86.9	71.4	21.9	100	41.1	70.5
1.25-1.5		10.3	7.8	9.3	3.7	1.5	7.7	6.5	0.0	3.4	10.2	6.0	1.9	17.6	6.3	5.9
	HH	63.0	84.8	77.7	75.6	89.3	79.7	65.0	9.2	42.9	52.8	90.9	100	73.9	73.6	79.0
>1.5	HL	0.0	0.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1.5	0.0	0.1
	NS	37.0	14.4	22.3	24.4	10.7	20.3	35.0	90.8	57.1	47.2	9.1	0.0	24.5	26.4	20.9
>1.5		20.8	19.7	19.9	16.6	11.4	19.0	26.1	41.2	29.3	25.2	14.9	29.3	39.4	13.5	18.8

Note: LL (Low-low), LH (Low-high), HL (High-low), HH (High-high), and NS (Not significant)

Discussion and Conclusion

The main goal of this research was to measure the geographical (spatial) accessibility to PHC services by applying the 3SFCA method and to identify neighbourhoods having poor accessibility to PHC services and their spatial patterns in urban settings. This research compares the results in 14 Canadian CMAs at both the urban area and neighbourhood level. This research demonstrates the benefit of using the 3SFCA method over simpler approaches in urban areas by providing similar results of city-level physician-to-population ratios with the advantage of intra-urban measurements. The results demonstrate that considerable spatial variation in potential geographical accessibility to PHC services exists within and across the CMAs selected for analysis. The results of this research show that Winnipeg has the lowest levels of access to PHC physicians (0.80 accessibility score) while Victoria has the highest (1.45 accessibility score); the difference between the minimum and maximum is 0.65. Moreover, this study focused on intra-urban variations in geographic access to care and found clusters of poorly served neighbourhoods in all urban areas. The most obvious finding to emerge from this is that 23.1 and 22.2 percent of the total population in 14 urban areas (total population: 11,659,364) fall into the first (< 0.50) and second (0.50-0.75) categories of accessibility scores, respectively. The largest population proportions (63.1 percent of 663,617 population and 54.8 percent of 1,096,184 population) in these categories (i.e., less than 0.50 and 0.50-0.75) are found in Winnipeg and Calgary respectively. This shows the significance of measuring geographical accessibility of PHC services at local levels for decision makers, planners, researchers, and policy makers in the field of public health and health geography.

It should be noted that only those physicians who fall in the category of *Family Doctors*, *Family Physicians*, *General Practitioners,* or *Non-Specialists* and have valid geocodeable

addresses are included in this study. Physicians having no address (68 in total) and having Post Office Box (P.O. Box) information (202 physicians) were removed. This omission of non geocodeable addresses may underestimate the accessibility to PHC services. The presence of such addresses in the analysis would increase the positional uncertainty of geocoded locations (Goldberg, et al., 2007) which could change the overall research findings (Hurley, Saunders, Nivas, Hertz, & Reynolds, 2003). It should also be noted the DA centroids, which represent the health care demand sites and geocoded locations of PHC services that may carry some positional errors, were used in the 3SFCA method and may generate some biases in the research findings (such as, considerable impact on the results of spatial regression analysis (Griffith, Millones, Vincent, Johnson, & Hunt, 2007), inaccurate results at finer-scale analysis (Zandbergen, 2007), etc. are reported; for a detailed overview of the potential biases in health research, see (Jacquez, 2012)). As this study did not consider population and physician data for neighbouring municipalities in all urban areas, edge effects may also be present. Geographical accessibility to only those physicians who accept new patients could be calculated to demonstrate the shortage of PHC services in urban areas, however in this research we are more interested in demonstrating the benefit of the 3SFCA accessibility score in identifying under served or poorly-served neighbourhoods, exploring the spatial patterns within urban settings, and comparing the results at both city and local levels as well.

The present study confirms previous findings (Bell, et al., 2013; Bell, et al., 2012; Bissonnette, et al., 2012) and contributes additional evidence that the 3SFCA method is an important addition to the public health, epidemiology, health planning, health geography, and related fields in calculating measures of geographical accessibility to health care (physician-to-population ratios) at both urban and intraurban levels (i.e., local or neighbourhood scale). In

addition, the 3SFCA method has great potential to be used in other areas such as measuring spatial accessibility to dental, HIV and rehabilitation, and mental health care services. Another important practical implication is that intra-urban patterns of geographical accessibility to PHC services can be utilized in physician workforce planning by provincial and regional decision makers, and in the process of urban area development by city planners.Future research could investigate the relationship between geographic accessibility to PHC services and socio-demographic characteristics in urban settings.

The findings of this study have a number of policy implications for improving geographic accessibility to health care services in Canadian urban settings. Information on geographic accessibility to health care services should be measured on a regular basis to observe changes in under-served regions and, through web-mapping, shared with physicians; particularly those who are looking to start new practice, those who are in training/newly graduated, or those who wish to change their practice locations. This information on the distribution of health care services and their proximity to homes would be useful for policymakers, researchers, city planners, community workers, and those residents who need services. In this regard, a standardized and compatible physician and clinic database (or directory) at a national level that is well linked with provincial databases (College of Physicians and Surgeons) would be helpful in measuring accessibility at local scales and would aid in mapping service locations. Further, information on a physician's working hours, hours by location, language skills, whether they are accepting patients etc., as a part of this national physician database would be beneficial in exploring other aspects of geographic accessibility and its links with contextual and socio-demographic factors as well.

CHAPTER 4: THIRD MANUSCRIPT

GEOGRAPHICAL ACCESSIBILITY TO PHC SERVICES IN CANADIAN URBAN
SETTINGS: EXAMINING THE ASSOCIATION WITH LOCAL AREA SOCIAL-
DEMOGRAPHIC CHARACTERISTICS

Authors: **Shah, T. I.**, Bell, S., & Wilson, K.

TS conceived and designed the study with SB, assembled input data, analyzed and interpreted
the data, and wrote the manuscript.

In chapter 4, the relationship between the geographical accessibility to PHC services and socio-

demographic characteristics is examined which is helpful in examining the distribution of PHC

services with respect to population health needs across 14 Canadian urban areas. To model this

relationship, a spatial regression method is applied.

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CHAPTER 4
GEOGRAPHICAL ACCESSIBILITY TO PHC SERVICES IN CANADIAN URBAN
SETTINGS: EXAMINING THE ASSOCIATION WITH LOCAL AREA SOCIAL-
DEMOGRAPHIC CHARACTERISTICS

Abstract

Access to primary health care (PHC) in urban centres is a relatively unstudied but important topic. This research determines whether there is an association between geographical accessibility to PHC services and socio-demographic characteristics in 14 Canadian cities. Using the Three-step Floating Catchment Area (3SFCA) method, a neighbourhood level physician-to-1000 population accessibility score was calculated. A set of socio-demographic characteristics as proxy for the determinants of health care needs was derived from 2006 census data. Census data was collected for dissemination areas (DA) and aggregated to the neighbourhood level. Initially, a best OLS regression model was estimated using a forward step-wise approach. To diagnose the presence of spatial effects in the regression residuals, Moran's I statistics were calculated. Strong spatial dependence in the outcome variable was present; a spatial lag regression model was used to control for spatial autocorrelation. In the spatial model, four explanatory variables, five regions, and a spatially lagged parameter were found associated with the accessibility score. Additionally, neighbourhoods with low accessibility scores and high health care needs were identified using bivariate spatial autocorrelation technique. Assessing the association between neighbourhood geographical accessibility and socio-demographic characteristics is helpful in examining the distribution of PHC services with respect to population health needs.

Keywords: spatial accessibility; primary health care; health geography; spatial statistics; census-based socio-demographic characteristics

Introduction

Access to Primary Health Care (PHC) is essential to ensuring all people receive adequate health care. Understanding the relationship between geographic access to primary care and socio demographic variability is an essential step in this process. The importance of place as a health care variable has developed rapidly in geography (Nykiforuk & Flaman, 2008) and is central to a clear understanding of public health policy and practice, as well as for the development of best practices. In any health care delivery system, the link between service provider and consumer has great importance (Meade & Earickson, 2000). Access to health care relies on a link between consumers and the system, this link varies across space (Penchansky & Thomas, 1981). In health geography, access has received various interpretations by policy makers and researchers (Birch & Abelson, 1993). According to Humphreys and Smith (2009), access is the capacity of the people to obtain healthcare at the right place and right time regardless of location, socioeconomic factors, or cultural background. In recent years, considerable progress has been made in our understanding of accessibility; however, new methods that address accessibility at different scales are needed. Generally, there are two domains of research that explore opportunities for good health (Andrews, 2002) and contributing to health policy in Health Geography: 1. disease ecology involving the diffusion and spatial distribution of disease, and 2. health service accessibility and utilization (Luginaah, 2009). In urban settings, people face similar challenges to those living in rural communities in terms of finding family physicians (Sibley & Weiner, 2011), but the distribution of and access to primary health care services in urban areas needs additional attention and a different perspective to ensure "comprehensive care for patients and their families within the community, with a focus on prevention, management of chronic disease, and coordination of care" (Scott & Chami, 2013). This research will explore whether there is a

relationship between geographical accessibility to PHC services and the socio-demographic characteristics of nearby populations in Canadian urban settings.

In recent years, the role of Geographic Information Systems (GIS) to measure accessibility, particularly the geographic dimension of access to health care services and to examine spatial inequalities in health care delivery has greatly improved the accuracy and sophistication of analyses (Cromley & McLafferty, 2002; Higgs, 2004; Humphreys & Smith, 2009; McLafferty, 2003). GIS makes integrating spatial and non-spatial data easy; as a result, researchers can perform spatial analysis (spatial statistics) to find acceptable solutions for health care delivery and health disparities (McLafferty, 2003). In order to study the relationship between a response variable (such as health care services, diseases distribution, etc.) and explanatory variables (e.g., demographic, social economic status, contextual or area characteristics, etc.) in health geography, spatial regression methods (or spatial econometrics) are increasingly used to incorporate contextual aspects into spatial data analysis (Baller, Anselin, Messner, Deane, & Hawkins, 2001; Bertazzon, Olson, & Knudtson, 2010; Chi, Zhou, & Voss, 2011; Duncan et al., 2012; Mobley, et al., 2006; Schmidtner et al., 2012; Ward & Gleditsch, 2008; Weidmann, Schneider, Litaker, Weck, & Klüter, 2012). The main advantage of the spatial regression models over typical regression models, such as ordinary least square regression, is to account for spatial autocorrelation, which is done by introducing a spatial weights matrix. A weights matrix labels the spatial relations (or spatial proximity) between the spatial units (areas) of analysis. The definition of what constitutes a neighbour depends on the type of spatial data (in this case areas) and the method used to define proximity (e.g., based on adjacency or a function of distance). For this study, spatial linear regression technique and local spatial autocorrelation

based on Moran's I Statistics are used to uncover the association between geographic accessibility to PHC services and socio-demographic variables at local scale.

Materials and Methods

Data sourcing and preparation

This study was carried out for 14 Canadian urban areas. A location map illustrating study areas is shown in Figure 4-1 (see locator map). Each urban area consists of at least one municipality (census subdivision) and locally relevant neighbourhoods are used as the units of analysis (the neighbourhoods as defined by the local government/planning authority). An accessibility score that characterizes the geographic accessibility to PHC services is used as the outcome variable. The focus is to determine whether there is an association between geographical accessibility to PHC services and socio-demographic factors in urban settings, we provide only a brief description of the outcome variable here. The accessibility score was calculated using a Three-Step Floating Catchment Area (3SFCA) method, which is a GIS-based procedure for urban settings that estimates geographical (potential) accessibility at a local scale (e.g., neighbourhood, census tract, etc.) in the form of a healthcare provider-to-population ratio (such as physician-to-1000 population)(Bell, et al., 2013; Bissonnette, et al., 2012). Physician-to-population ratios for each PHC service location are calculated in the first step of this method. Dissemination area (DA) centroids are used to represent population settings and service catchment areas are determined by using 3km road network distance from the geocoded locations of PHC services. A total of 5,066 practice sites, in 14 urban areas where 11,523 physicians were providing PHC services, are considered. A integrated geocoding technique was applied to generate the

geographic coordinates (Bell, et al., 2012; Shah, et al., 2014). In the second step, the DA

centroids were used along with catchment areas created using 3km road network distance. In the

third step, a neighbourhood physician-to-population ratio (i.e., accessibility score) was generated

by aggregating the step 2 ratios. For further details on how this variable was calculated, see

(Shah, Bell, & Wilson, Revise and Resubmit). For a more detailed description of the 3SFCA

method, see (Bell, et al., 2013; Bissonnette, et al., 2012; Luo, 2004). For all 14 urban areas, a set

of maps showing the spatial patterns of the 3SFCA accessibility scores was produced (see Figure

4-1) that displays a general distribution pattern. In all cases, higher scores are clustered in the

core urban neighbourhoods whereas lower scores are further away from the core neighbourhoods

to the edges of the urban areas. An error bar graph of accessibility scores for urban areas (with

95% confidence interval for mean) is shown in Figure 4-2, which shows differences in

geographic accessibility to PHC services across Canadian urban areas. These variations in

accessibility scores among urban areas and their comparison with city level physician-to-

population ratios are described elsewhere in detail (Shah, et al., Revise and Resubmit).
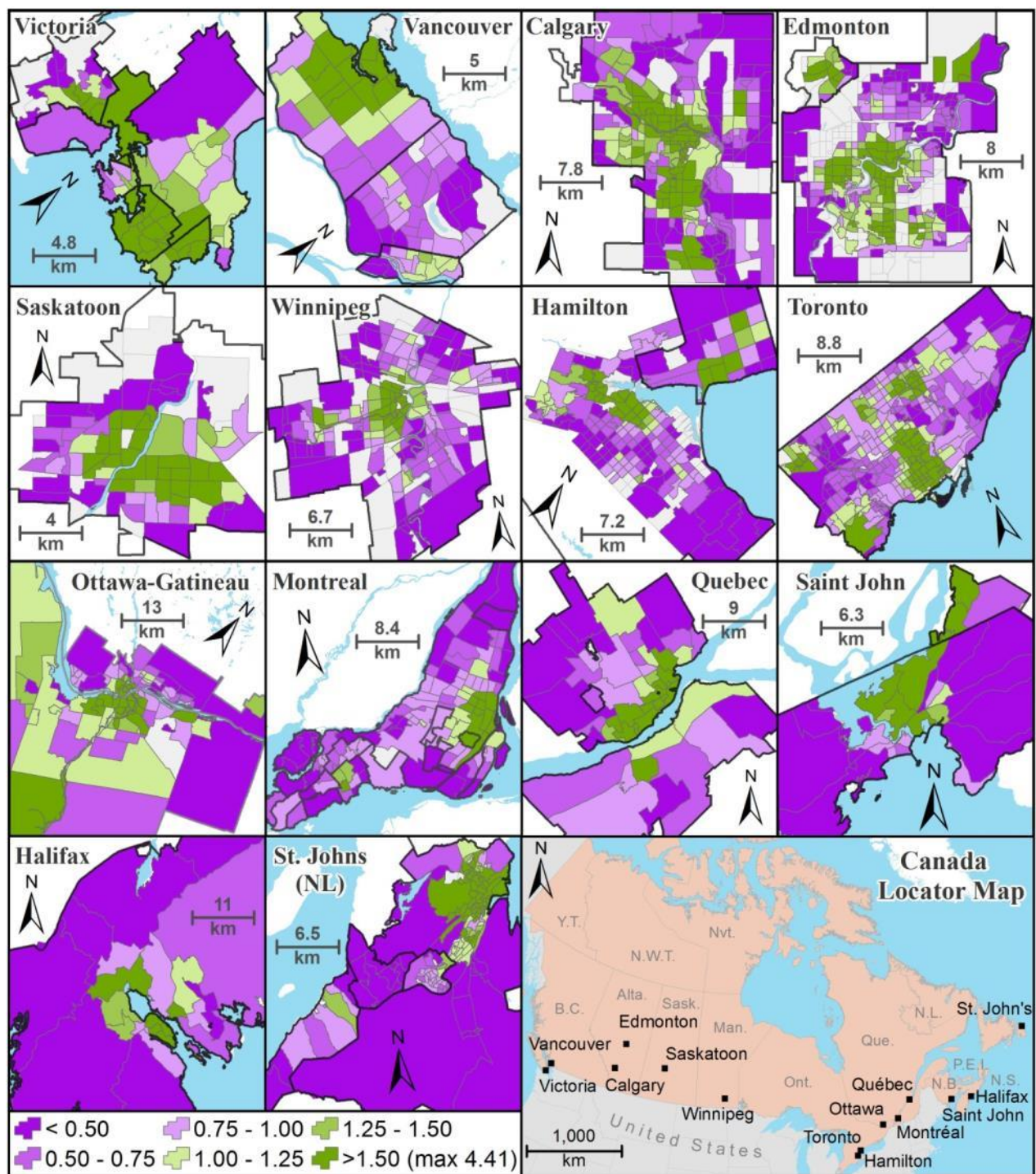
Figure 4-1. Study area map **(a)** Locator map shows the location of Canadian urban areas. **(b)** The rest of the map windows are displaying the 3SFCA accessibility score classified into six categories (note that neighbourhood scores from all 14 urban areas together are used in this classification). The mean accessibility score for each city is indicated in square brackets.
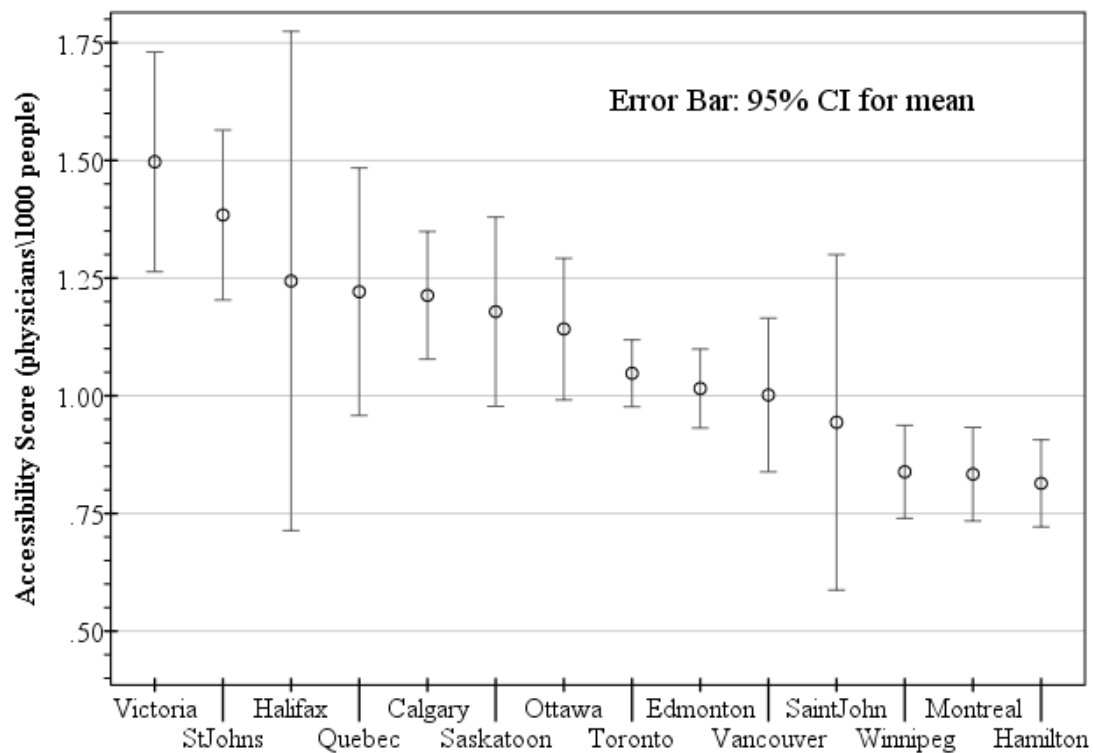
Figure 4-2. Error bar graph of 3SFCA accessibility score in Canadian urban areas

Potential relevant variables

Based on census data, a relevant set of socio-demographic characteristics to proxy for

determinants of health status or health care needs were identified by considering the contextual

factors presented in recent influential studies in the field (Andersen & Davidson, 2001; Bell &

Hayes, 2012; Field, 2000; Pampalon et al., 2012; PHAC, 2012; Wang & Luo, 2005). In Canada,

a large and growing body of literature incorporating census data for analyzing health disparity at

local scales draws our attention to an increasing and observable trend in health geography (Bell

& Hayes, 2012; Chateau, Metge, Prior, & Soodeen, 2012; Matheson, Dunn, Smith, Moineddin,

& Glazier, 2012; Pampalon, et al., 2012). Keith and Davidson (2012) describe this trend in the

following way:

"…….deficiencies in (micro-level) data, the emergence of a conceptual and theoretical concern with "place" and health, and an emerging imperative to ground research on social inequalities in health in order to facilitate the production of evidence that can inform place-based action."

For this study, ten variables were shortlisted based on theoretical significance and data availability. A list of these census-based socio-demographic explanatory variables along with brief descriptions is given in Table 4-1. These explanatory variables were derived from the 2006 Canadian census. Census data was collected at the DA level (Statistics Canada) and aggregated to neighbourhoods. One of these variables, population with high healthcare need, is a composite variable of the following: children between ages 0-4, seniors with ages above 65, and women aged 15-44 (Wang & Luo, 2005). Note that all of the explanatory variables were expressed as percentages. For descriptive statistics that include variable mean and standard deviation, see Table 4-2.

Table 4-1. List of census-based socio-demographic characteristics that help in examining the distribution of PHC services with respect to population health needs

Category	Variable	Description
Demographic Variables	Population with high need for Healthcare	Percent of population by high needs for PHC services (population groups: children with ages 0-4, seniors with ages above 65, and women with ages 15-44)
	Persons 65 years and over living alone	Percent of population 65 years of age and over living alone
Socioeconomic Status (SES)	Lone-parent families	Percent of single (lone)-parent families among all census families (single-parent)
	Low income persons/ Prevalence of low income	Percent of persons in economic families below the Statistics Canada low-income cut-off (LICO) after tax (For detailed information, see (Statistics Canada, 2007a))
	Unemployment rate	Unemployed population (individuals) of age 15 years and over divided by the total population of age 15 years and over participating in the labour force.
Environment	Home ownership	Percent of dwellings occupied by the owner
	Dwellings in need of major repairs	Percent of dwellings in need of major repairs (major repairs refer to the repair of defective plumbing or electrical wiring, structural repairs to walls, floors or ceilings, etc.)
Service Awareness	Aboriginal Population	Percent of aboriginal identity population
	Recent Immigrants	Percent of immigrants who came to Canada from 2001-2006
	No school education	Percent of population 15 years and older without high school certificate, diploma or degree
Regional variables	13 city dummy variables	Calgary dummy variable is 1 if city name is Calgary, 0 if not; and same procedure was applied for other twelve dummy variables except Ottawa-Gatineau

Spatial Analysis and Results

In this study, after considering explanatory variables, unit of analysis, and regional aspects in the form of 14 urban areas across Canada, a spatial linear regression technique was applied to examine the association between neighbourhood socio-demographic characteristics and geographic accessibility to PHC services. This study involves 14 urban areas that are well

distributed across Canada; each city acts like a distinct region (or additional variable). To account for the regional influences in statistical modeling (Erjavec, 2011, p. 407; Huang, Zhu, & Deng, 2007; Ying, 2003), we employed regional dummy variables (k-1= 13) to capture the city level differences; in this case the Ottawa - Gatineau urban area was used as the reference city (see Table 4-1). This is consistent with a number of studies that have applied spatial regression analysis by incorporating dummy variables (e.g., Chi & Zhu, 2008; Messner & Anselin, 2004; Schmidtner, et al., 2012; Ying, 2003). Generally, use of one of the dummy variables as a reference or a control variable is to avoid a situation of perfect multicollinearity when the regression model cannot be estimated (Baltagi, 2011, p. 81; Erjavec, 2011). In this case, Ottawa – Gatineau was selected as the reference because its accessibility score was closest to the mean accessibility score using the 3SFCA (see Figure 4-2). An alternative approach to dealing with the city level differences would involve multilevel modeling. Multilevel modeling, as Lloyd (2011, p. 108) states, "is generally concerned with the separation of effects of personal characteristics and place characteristics (contextual effects) on behavior," and use of this method can be found in health research with spatial hierarchies (Diez-Roux, 2000; Langford & Bentham, 1996; Langford, Bentham, & McDonald, 1998; Lloyd, 2011, pp. 108-109; Oka, Link, & Kawachi, 2013; Vanoutrive & Parenti, 2009; Zhang, Onufrak, Holt, & Croft, 2013). Multilevel modeling has many advantages over other classical regression techniques (for example, to overcome the effects due to the atomistic and the ecological fallacies, for details, see (Gelman & Hill, 2007; Snijders & Bosker, 2012; Vanoutrive & Parenti, 2009)), but in our case spatial linear regression with dummy variables is an appropriate choice as the dataset used is in continue space for which spatial modeling technique are more appropriate (Chaix, Merlo, & Chauvin, 2005). Moreover, our data do not have the required number of groups to ensure sufficient statistical power or an

adequate number of hierarchical levels (i.e., at least 30 groups, for discussion on this see Hox, 1998).

For the purpose of analysis, a best-fit OLS regression model (higher R-squared value) was identified. In order to achieve this, we employed a forward stepwise linear regression method to identify possible models for spatial analysis. After analyzing the descriptive and collinearity statistics - tolerance and variance inflation factor (VIF), as discussed by (Allison, 1999, pp. 141-142), the following variables were excluded from further analyses: 1) Persons 65 years and over living alone, and 2) Home ownership. We re-ran the regression procedure and selected the best model by considering adjusted R-square values and coefficients at the 5% significance level. All above-mentioned regression procedures were performed with IBM SPSS Statistics 20 (IBM Corp, 2011). Neighbourhoods having no population data were excluded from the analysis (n = 244). Note that DAs with less than 40 persons we excluded as their data is not available for public use; these DAs represent less than two percent of the total in this study (54,626 in total). Descriptive statistics and global spatial autocorrelation for variables of interest are given in Table 4-2. The Moran's I statistic indicates the presence of global spatial autocorrelation for the dependent and explanatory variables.

To detect the presence of spatial effects, particularly spatial autocorrelation in the regression residuals, we recalculated the selected OLS model with spatial weight matrix - queen contiguity (first order neighbours, row-standardized). Following the regression diagnostics for spatial dependence (i.e., Lagrange multiplier robust tests (Anselin, 1988)) as shown in Table 4-3, a spatial lag regression model with a spatially lagged dependent variable, and spatial weight matrix (queen contiguity, row-standardized) was estimated by applying maximum likelihood to reduce the spatial autocorrelation present in the OLS model. A comparison of the estimates

between non-spatial (OLS) and spatial (lag) regression models are shown in Table 4-4. The

spatial regression analysis was performed using GeoDa software (Anselin, et al., 2006; Anselin,

Syabri, & Kho, 2010).

Table 4-2. Descriptive statistics and global spatial autocorrelation for selected variables

Variables (N=1774)	Mean	Std. Deviation	Moran's I*
Accessibility score	1.06	0.79	0.716
Population with high needs for Healthcare	40.81	5.27	0.258
Lone-parent Families	17.86	8.40	0.355
Aboriginal Population	3.09	5.17	0.707
Recent immigrants (2001-2006)	4.49	5.13	0.540
Population w/o high-school certificate	20.10	9.07	0.616
Low income persons	13.89	10.19	0.472
Unemployment rate	6.09	3.35	0.387
Dwellings in need of major repairs	6.61	4.30	0.385
With 13 regional dummy variables (Ottawa – Gatineau as a reference region)			

[*]All Moran's I values are significant with $P < 0.05$.

Table 4-3. Diagnostics for Spatial Dependence: Lagrange Multiplier Tests

Test	MI/df	Test value	Probability
Moran's I (error)	0.484	32.12	0.000
Lagrange Multiplier (lag)	1	1290.90	0.000
Robust LM (lag)	1	305.04	0.000
Lagrange Multiplier (error)	1	988.14	0.000
Robust LM (error)	1	2.28	0.131
Lagrange Multiplier (SARMA)	2	1293.18	0.000

The measures for goodness of fit for the OLS regression and spatial lag models are compared using the Akaike Information Criterion (AIC) and Log likelihood. The spatial lag model performed better than OLS in terms of AIC and Log Likelihood (AIC 3412.1 to 2052.2 and Log likelihood -1693.1 to -1012.1), but could not successfully overcome the spatial autocorrelation in the model residuals (see Table 4-4, a significant Moran's I 0.039 in spatial lag model whereas 0.484 was found in OLS at the 5% significance level). Furthermore, all but two explanatory variables that were statistically significant in OLS regression remained as significant predictors in the spatial lag model; the two variables that were no longer significant were recent immigrants and two of the regional variables (Hamilton, ON and Victoria, BC), (see, Table 4-4). In the selected spatial lag model, four explanatory variables, five regional variables, and a spatially lagged parameter (rho) were found associated with the geographic accessibility to PHC services (For details, see Table 4-4). The presence of a positive spatial lag (rho = 0.813) in the regression model indicates that the accessibility scores in adjacent neighborhoods are related. Note that ignoring spatial dependence could lead to biased coefficient estimates. The following variables were significant predictors: low-income persons, population without high-school education, population with high needs for healthcare, and dwellings in need of major repairs. The spatial lag regression results also identified the regional differences in geographical accessibility to PHC services. The regional variable for Montreal, Vancouver, Toronto, and Winnipeg identified lower accessibility scores (i.e., 19.9%, 17.9%, 10.9%, and 8.8% respectively) and for St. Johns found 9.6% higher scores than that in the Ottawa-Gatineau as shown in the Table 4-4. The remaining eight urban areas revealed no significant variation in geographical accessibility to PHC services compared to the reference city.

Table 4-4. A comparison between the estimates of non-spatial (OLS) and spatial (lag) models

Model (best)	Coefficient (SE)	
	OLS Regression	**Spatial Lag**
(Constant)	0.324 (0.124)**	-0.209 (0.075)**
Low income persons (LICO after tax)	0.039 (0.002)***	0.012 (0.001)***
Pop. w/o high-school education	-0.043 (0.002)***	-0.013 (0.001)***
Recent immigrants (2001-2006)	-0.018 (0.004) ***	-0.002 (0.002)
Pop. with high needs for healthcare	0.027(0.003)***	0.012 (0.002)***
Dwellings in need of major repairs	0.03(0.004)***	0.009 (0.003)**
Spatially lagged parameter (Rho)		0.813 (0.012)***
Regional variables (dummy)		
Montreal	-0.684 (0.065)***	-0.199 (0.04)***
Vancouver	-0.529 (0.081)***	-0.179 (0.049)***
Winnipeg	-0.382 (0.053)***	-0.088 (0.032)**
Toronto	-0.291 (0.048)***	-0.109 (0.029)***
St. Johns	0.229 (0.061)***	0.096 (0.037)**
Hamilton	-0.214 (0.054)***	-0.033 (0.033)
Victoria	0.188 (0.084)*	-0.01 (0.051)
R Square	0.37	0.77
SE of the Estimate	0.63	0.38
df	1761	1760
Akaike Information Criterion (AIC)	3412.1	2052.2
Log Likelihood	-1693.1	-1012.1
Moran's I	0.484***	0.039**

Note: regional variables (Ottawa – Gatineau as a reference region)
*p <0.05; **p < 0.01; ***p<0.001.

For further understanding of the relationship between accessibility score and socio-demographic variables described above, we studied the local variations in the geographical accessibility to PHC services at the neighbourhoods level across Canadian urban settings. In order to achieve this, we analyzed the spatial association of accessibility scores: 1), with itself, and 2) with in combination of significant explanatory variables. First, a local indicator of spatial autocorrelation (LISA) statistic was used to identify local clusters of accessibility. LISA is one of the ways to measure local spatial association (i.e., local forms of Moran's I) (Anselin, 1995). The Moran's I statistic, a global test, indicates the presence of clusters whereas local Moran's I indicates the location of clusters and the type of spatial association as well. In health geography, many studies have been published using the LISA technique to identify spatial patterns (Odoi et al., 2003; Pouliou & Elliott, 2009; Shrestha et al., 2012; Tu, Tedders, & Tian, 2012). In this case, the association of the accessibility score for a particular neighbourhood is assessed with its adjacent neighbourhoods as well as with the national average (Anselin, 1995). A permutation approach that tests the significance of this association was applied. More information on global and local measures of spatial autocorrelation can be found elsewhere (Lloyd, 2011, pp. 80-99; Wong & Lee, 2005, pp. 367-405). As a result of this analysis, all neighbourhoods were classified into five categories; 1) high-high (HH), 2) low-low (LL), 3) high-low (HL), 4) low-high (LH), and 5) not significant (NS). The first two categories (HH, LL) indicate the presence of positive spatial autocorrelation, whereas the next two categories (HL, LH) indicate negative spatial autocorrelation. The latter association means that (high/low) accessibility scores are significantly correlated with (low/high) adjacent neighbourhood values, respectively. A set of maps prepared using a univariate Local Moran's I tool on 14 urban areas together to illustrate local clusters of accessibility score across urban settings is shown in Figure 4-3.

Table 4-5. Neighbourhood (NH) count of low-high (LH) clusters between accessibility scores and the all four significant predictors.

| Urban areas	Total NGH	Low income persons	Pop. with high needs for health care	Dwelling in need of major repairs	Pop. without high-school education	All four predictors
	n	*n (%'row')*	*n (%'row')*	*n (%'row')*	*n (%'row')*	*n (%'row')*
Calgary	204	5 (2.5)	4 (2.0)	1 (0.5)	25 (12.3)	31 (15.2)
Edmonton	249	4 (1.6)	14 (5.6)	7 (2.8)	39 (15.7)	48 (19.3)
Halifax	23	-	-	-	-	-
Hamilton	172	8 (4.7)	18 (10.5)	18 (10.5)	51 (29.7)	62 (36.0)
Montreal	116	31 (26.7)	6 (5.2)	26 (22.4)	14 (12.1)	48 (41.4)
Ottawa	92	1 (1.1)	-	2 (2.2)	13 (14.1)	13 (14.1)
Quebec	49	-	-	-	-	-
Saint John	32	-	-	7 (21.9)	4 (12.5)	7 (21.9)
Saskatoon	67	5 (7.5)	5 (7.5)	3 (4.5)	13 (19.4)	19 (28.4)
St. John's	133	2 (1.5)	1 (0.8)	1 (0.8)	4 (3.0)	5 (3.8)
Toronto	318	45 (14.2)	30 (9.4)	25 (7.9)	45 (14.2)	91 (28.6)
Vancouver	72	4 (5.6)	-	9 (12.5)	-	13 (18.1)
Victoria	62	-	1 (1.6)	-	-	1 (1.6)
Winnipeg	185	8 (4.3)	11 (5.9)	34 (18.4)	25 (13.5)	53 (28.6)
Total	1774	113 (6.4)	90 (5.1)	133 (7.5)	233 (13.1)	391 (22.0)
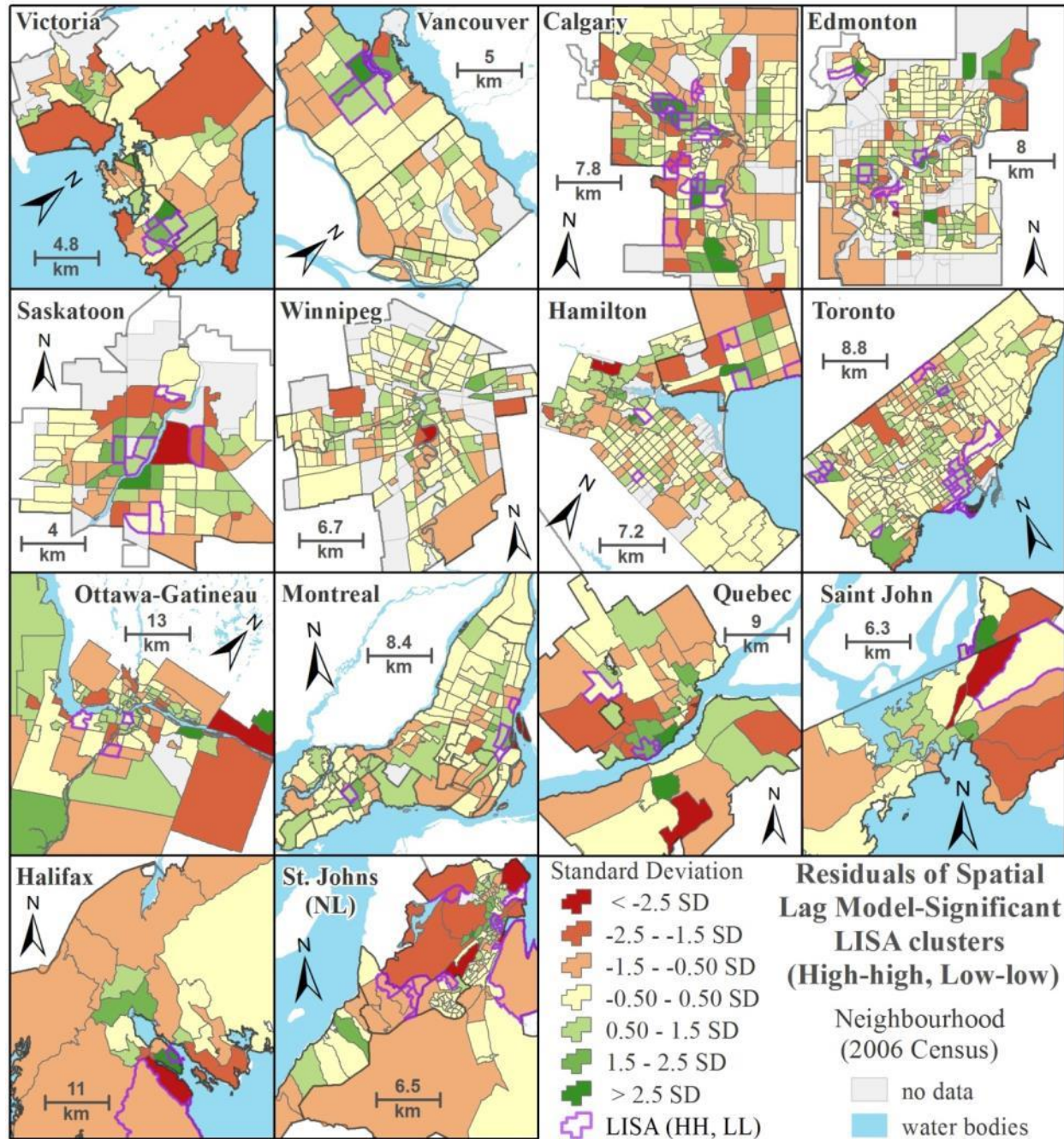
Figure 4-3. Distribution of residuals from spatial lag regression model with significant spatial clusters

Second, bivariate measures of spatial autocorrelation, an extension of the univariate

LISA, was applied to locate spatial clusters of accessibility score in association with the

significant explanatory variables. The purpose of this step is to identify neighbourhoods across urban areas with low accessibility scores and high health care needs. In health geography, bivariate LISA (BiLISA) is normally used to highlight areas for targeting future interventions. For example, Highfield (2013) used this technique to locate areas (i.e., census tracts) where low breast cancer incidence is associated with high incidence of uninsured women "to assess mammography screening behaviors and barriers to screening at the local level." The BiLISA measures the spatial correlation between two different variables, one taken from a target neighbourhood and the second taken from that target's neighbours. In our case, there are four significant explanatory variables that were found as a result of spatial regression. The BiLISA process was applied repeatedly to all four explanatory variables using accessibility as the target variable (i.e., geographic accessibility to PHC services). Similar to univariate LISA categories, BiLISA classified all neighbourhoods into five categories (high-high, low-low, low-high, high-low, and not significant) (see, Figure 4-4a and 4b). Geoda is used to compute uni-and bi-variate local Moran's I (local LISA) (Anselin, et al., 2006, 2010) and the thematic maps shown in Figures 4-3 – 4-4 are prepared using ArcGIS software (ESRI, 2012). In BiLISA maps, the significant low-high (LH) clusters indicates low accessibility score neighbourhoods surrounded by high values for the explanatory variable in question. These are the most interesting and represent neighbourhoods with high demand of PHC services. Table 4-5 shows the number of neighbourhoods in each city that fall into this category. The number of neighbourhoods given in the last column of the Table 4-5 (column name) are a sum of all neighbourhoods in this category for all 4 explanatory variables without double counting neighbourhoods that fall this is category more than once. Overall, 391 neighbourhoods (22.0 %) that have low accessibility scores and high values in case of all socio-demographic variables are found.

Figure 4-4a. Bivariate LISA maps for accessibility score and following predictors. (a) Low income persons. (b) Pop. without high-school education. (c) Pop. with high needs for healthcare. (d) Dwellings in need of major repairs.
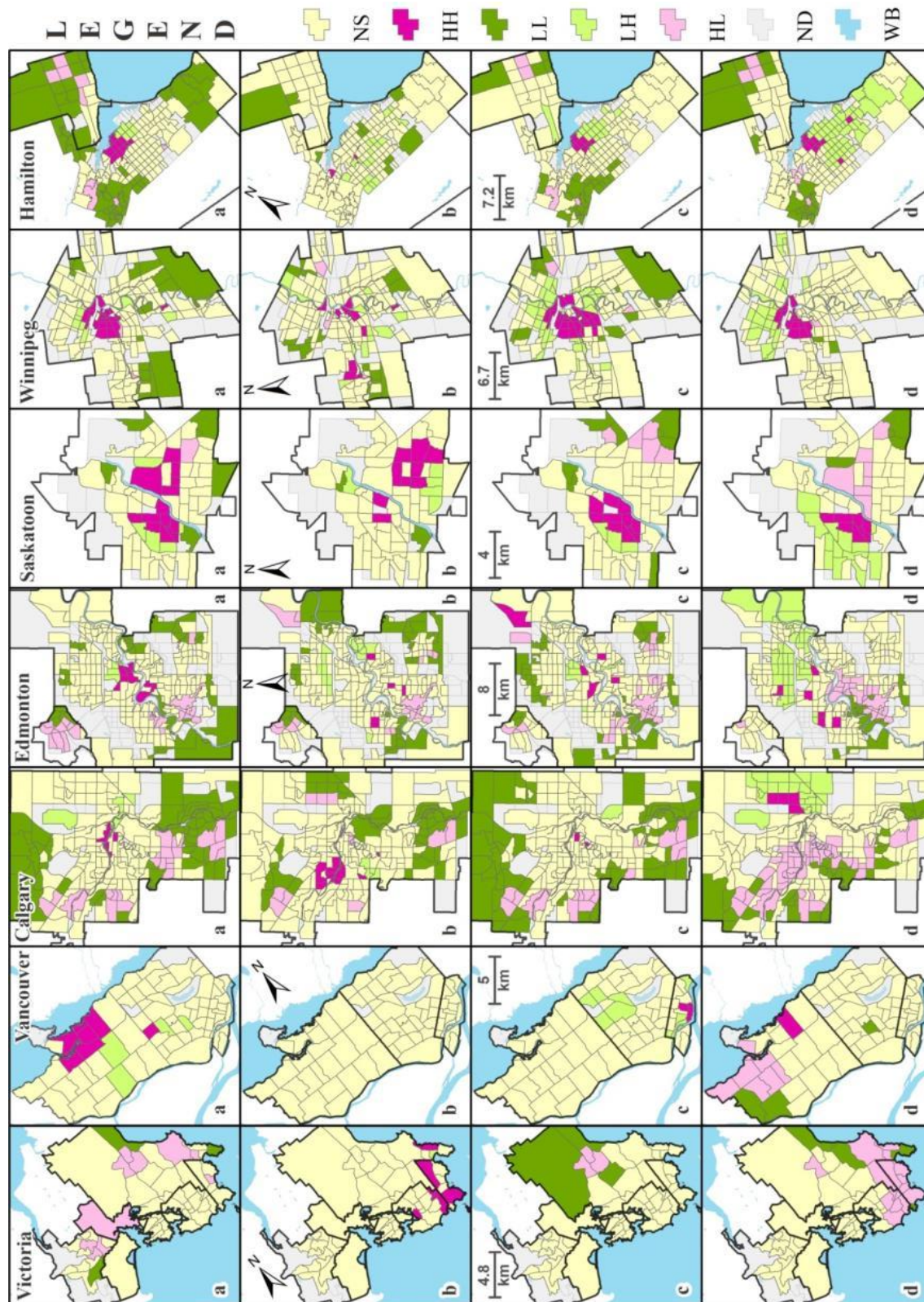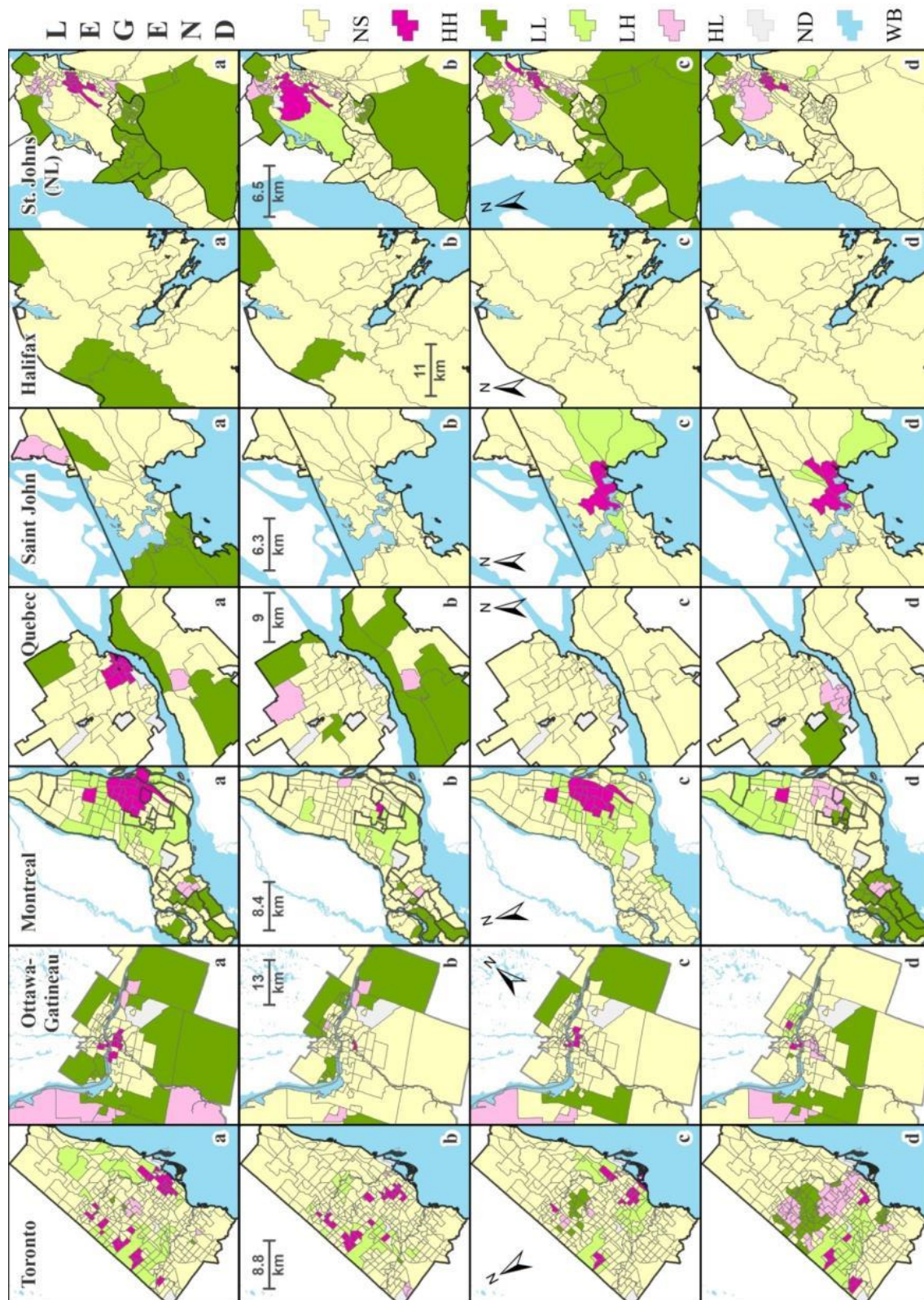
Figure 4-4b. Bivariate LISA maps for accessibility score and following predictors. (a) Low income persons. (b) Without high-school education. (c) High needs for healthcare. (d) Dwellings repairs.

Discussion

Our results show that census based socio-demographic characteristics that include prevalence of low-income (LICO), population without high-school education, population with high needs for healthcare, and dwellings in need of major repairs, are associated with geographical accessibility to PHC services in Canadian urban settings. We also identified neighbourhoods with poor geographical accessibility to PHC services (3SFCA accessibility scores) in association with high health care needs (or in other words high proportions of these significant explanatory variables).

The few important limitations of this study that we need to discuss are related to physicians' selection criteria and procedure implemented in preparing data for analysis. The following categories of physicians: Family Doctors, Family Physicians, General Practitioners, or Non-Specialists, are included in measuring accessibility score. This selection was further refined by excluding non-geocodable addresses such as physicians having no address (68 in total) and having Post Office Box (P.O. Box) information (202 physicians), and physicians practicing outside the municipal boundaries. This omission of non-geocodeable addresses and practices outside the municipal boundaries from analysis may influence the accessibility to PHC services (Goldberg, et al., 2007; Hurley, et al., 2003). In the 3SFCA method, the healthcare demand sites are represented by DA centroids and locations of PHC services are generated using integrated geocoding process that may carry some positional errors, which could result in biases in the research findings. We did not consider the data that lay outside the municipal boundaries both in the estimation of accessibility scores, as well in modeling process, which could influence the results near the edge of the each city.

Relationship between the accessibility score and the socio-demographic variables

It is evident from the non-spatial and spatial models that the socio-demographic characteristics are associated with accessibility score. Spatial model explains the variation in accessibility score better than non-spatial model (77 percent in case of spatial model). Based on spatial regression, higher proportion of the following variables; population with high needs for healthcare, low-income persons, and dwellings in need of major repairs are found associated with better geographic accessibility to PHC services in Canadian urban settings. Population without high-school level education has a thought-provoking relationship with accessibility score; surprisingly, the higher proportion is associated with smaller accessibility scores whereas it is positively correlated with the other three significant predictors. Interestingly, a 10 percentage point change in any one of the four predictors would result in approximately 0.1 point (i.e., 0.1 physicians per 1000 people) change in accessibility score. The spatially lagged parameter (rho; 0.81) is directly associated with the dependent variable that indicates the neighbouring neighbourhood accessibility scores can be used to determine reliable estimates. The spatial lag model also includes the five regional variables for the following urban areas: Vancouver, Winnipeg, Toronto, Montréal, and St Johns which helps address the implications due to regional differences. With reference to the Ottawa-Gatineau, the coefficient estimate for the St. Johns indicates higher accessibility score whereas rest of the four city specific variables depicts lower accessibility scores. A set of LISA maps for all 14 urban areas indicates the bivariate association of accessibility score and selected predictors, particularly where low values of physician-to-1000 population ratio are associated with high proportions of the socio-demographic factors.

Predictor 1: Low income persons

This variable, an indicator the socioeconomic status (SES), is providing the information (in percentage) of persons that belong to the economic families below the Statistics Canada low-income cut-off (LICO) after tax (see, Statistics Canada, 2007a) at a neighbourhood scale. Across all urban areas, 113 neighbourhoods are found where low accessibility scores are associated with high proportion of low income persons (see Table 4-5, and Figures 4-4a and 4b). In comparison, four urban areas (Halifax, Quebec city, Saint John, and Victoria) show no significant LH clusters. Two urban areas (Montreal and Toronto) are found with the maximum proportion of neighbourhoods (26.7% and 14.2 % respectively) where low accessibility score are associated with high percent of low income population.

Predictor 2: Population with high need for healthcare

This demographic variable represents the proportion of certain population groups that includes children with ages 0-4, seniors with ages above 65, and women with ages 15-44 at neighbourhood level, which normally show a high needs for PHC services. Across all urban areas, 90 neighbourhoods are found where low accessibility scores are associated with high proportion of population with high needs for health care (see Table 4-5, and Figures 4-4a and 4b). In comparison, five urban areas (Halifax, Ottawa, Quebec city, Saint John, and Vancouver) show no significant LH clusters whereas Hamilton and Toronto show maximum proportion of neighbourhoods (10.5 %, and 9.5 % respectively).

Predictor 3: dwelling in need of major repairs

Dwellings in need of major repairs that includes the repair of defective plumbing or electrical wiring, structural repairs to walls, floors or ceilings, etc. is somehow connected to the environmental issues particularly at a local scale such as neighbourhood. 133 neighbourhoods are found where low accessibility scores are associated with high proportion of dwelling in need

of major repairs (see Table 4-5, and Figures 4-4a and 4b). In comparison, three urban areas (Halifax, Quebec city and Victoria) show no significant LH clusters whereas Montreal, Saint John, Winnipeg, Vancouver, and Hamilton show proportion of neighbourhoods over 10 percent (22.4 %, 21.9 %, 18.4 %, 12.5 %, and 10.5 % respectively).

Predictor 4: Population without high-school education

This variable provides information about population 15 years and older without a high school certificate, diploma or degree and is an important member of a group of service awareness variables that measures one's ability to utilize health care services well. 233 neighbourhoods are found where low accessibility scores are associated with high proportion of population without high-school education (see Table 4-5, and Figures 4-4a and 4b). In comparison, four urban areas (Halifax, Quebec city, Vancourver and Victoria) show no significant LH clusters and remaining urban areas except St. John's show proportion of neighbourhoods over 10 percent.

Association of all four predictors across urban areas

Comparisons of low accessibility scores in association with higher proportions of different predictors reveal variations in geographical accessibility to PHC services both within an urban area as well as across Canadian urban settings. Montreal, Hamilton, Saskatoon, Toronto, and Winnipeg, where more than 25 percent of the total number of neighbourhoods (41.4, 36.0, 28.4, 28.6, and 28.6 percent respectively), in all four predictors are elucidating distribution patterns. In the case of Halifax, Quebec city, St. John's and Victoria, the distribution of PHC services is in accordance with the population health care needs (see Table 4-5, Figure 4-4a and 4b). The proportion of the number of neighbourhoods in the remaining five urban areas ranges from 14.1

to 21.9 demonstrates the presence of uneven distribution of PHC services in association with high population health care needs. In contrast to the distribution pattern of accessibility scores, the lower scores are moving away from the core neighbourhoods to the edges of the urban areas as shown in Figure 4-1, the LH clusters can be found close to core neighbourhoods (for example, Montreal, Toronto, Hamilton, Winnipeg, etc.).

Conclusion

In urban settings, distribution of PHC services in association with population health care needs is a relatively unstudied topic. This study is a useful contribution in understanding the association of accessibility score with the socio-demographic characteristics in a Canadian urban context. With this study, the Three-step Floating Catchment Area (3SFCA) method, which was recently introduced to health geography (Bell, et al., 2013; Bissonnette, et al., 2012) is strengthened and is one of the key contributors in measuring geographical accessibility to health care services. Spatial statistical modeling and subsequent use of local Moran's I technique allowed identification of those neighbourhoods presenting a mismatch of accessibility scores and population health care needs, and could be also be used to further analyze how different units of analysis predict distribution of health care services in context of modifiable social factors at a local scale. Local spatial statistical modeling techniques such as geographically weighted regression (GWR) could be applied to address the spatial effects due to non-stationarity aspect of spatial data. An implication of these findings is that health and city planners should also consider socio-demographic factors while designing programs to support, facilitate, and guide physicians in practice site identification. If the concern of health policy is to accommodate the needs of residents with different socio-demographic characteristics, it will be highly recommended to first

assess the relationship of distribution of health care services with social-demographic factors, and then to identify poorly served pockets of urban fabric.

CHAPTER 5: FOURTH MANUSCRIPT

EXPLORING THE INTRA-URBAN VARIATIONS IN THE RELATIONSHIP AMONG
GEOGRAPHIC ACCESSIBILITY TO PHC SERVICES AND SOCIO-DEMOGRAPHIC
FACTORS

Authors: **Shah, T. I.**, & Bell, S.

TS conceived and designed the study with SB, assembled input data, analyzed and interpreted
the data, and wrote the manuscript.

Chapter 5 presents a case study of geographically weighted regression (GWR) in which the intra-urban variations in the relationships among the socio-demographic factors and geographical accessibility to PHC services are investigated. This chapter focusses on two Canadian urban areas (Calgary, AB and Toronto, ON) and highlights the significance of local spatial regression in disaggregating the relationships between socio-demographic variables and the geographical accessibility to PHC services at a local scale.

CHAPTER 5
EXPLORING THE INTRA-URBAN VARIATIONS IN THE RELATIONSHIP AMONG GEOGRAPHIC ACCESSIBILITY TO PHC SERVICES AND SOCIO-DEMOGRAPHIC FACTORS

Abstract

In this study, we investigate the intra-urban variations in the relationships among various socio-demographic factors and geographical accessibility to primary health care (PHC) services using a local regression model. Geographic accessibility to PHC services is calculated at a local scale for two Canadian urban centers (Calgary, AB and Toronto, ON) using a three-step floating catchment area (3SFCA) method. Socio-demographic factors were derived from 2006 Canada census data. The regression analysis was performed using two different methods: 1) a single regression model for both cities together, using a regional dummy variable, and 2) separate models for each city. A similar modeling procedure was applied for both methods: first, a best Ordinary Least Squares (OLS) regression model was determined using a forward step-wise approach in SPSS software. Next, to test the spatial non-stationarity in the regression residuals, the best OLS model was repeated in ArcGIS. Further, to explore whether or not regression coefficients vary across space, we applied the geographically weighted regression (GWR) method with an adaptive spatial kernel. The GWR results exhibit the intra-urban variations in the relationships between socio-demographic factors and the accessibility score. A comparison of the GWR models demonstrates the benefit of local spatial regression in disaggregating the relationships between socio-demographic variables and the geographical accessibility to PHC services at a local scale; however, our results suggest that a more careful modeling approach is required when analysing the data with spatial effects.

Keywords: Spatial non-stationarity, geographically weighted regression, urban geography, physician-to-population, geographic accessibility

Introduction

There are many challenges to health care delivery in urban areas. Among them is the relationship between the arrangement of primary health care facilities and the populations they are meant to serve. In this context, geographic accessibility to PHC services in association with health care needs is a critical and relatively unstudied topic. In Canada, access to health care is essential in ensuring all people receive adequate health care as near as possible to their residence (Government of Ontario, 2012). Geographic access to health care in relation to population health needs (or consumers) varies across space (Penchansky & Thomas, 1981). In health geography, the multivariate regression technique is normally used to determine the association of a response variable with explanatory factors; however, with current advancements in GIS, spatial data handling, and spatial statistics, spatial regression methods are increasingly used to address methodological issues as well as the contextual aspects of spatial data analysis (Bagheri, Holt, & Benwell, 2009; Baller, et al., 2001; Bertazzon, et al., 2010; Chi, et al., 2011; Duncan, et al., 2012; Holt & Lo, 2008; Mobley, et al., 2006; Schmidtner, et al., 2012; Ward & Gleditsch, 2008; Weidmann, et al., 2012). The main advantage of spatial regression, in addition to increasing the reliability of regression measures, is to explore the spatial variation between variables. This is typically achieved by focusing on certain spatial effects that normally exist in spatial data. Two types of spatial processes that can affect regression estimates are considered for regression models in geography: spatial autocorrelation and spatial non-stationarity (heterogeneity) (as discussed by Griffith et al., 2013, p. 16). Spatial autocorrelation is related to spatial dependence

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in regression residuals, and can often result in misleading outcomes for coefficient significance tests. Spatial non-stationarity in spatial data modeling indicates that the variance of residuals is different across the space in question. There is no practical modeling solution to address both spatial effects in a single modeling framework except for the possibility of a 'geographically weighted version of a spatial regression model' (Fotheringham, 2009). Local models have several comparative advantages over global spatial regression, these include: local regression coefficients, mappable regression parameters, and local hot-spot identification (Fotheringham, Brunsdon, & Charlton, 2002, pp. 6-7). Furthermore, the process of calibrating local models can accommodate the problem of spatial dependency in regression residuals (Fotheringham, 2009; Fotheringham, et al., 2002).

In this research, we focus on local spatial regression to model geographical accessibility to PHC services in urban settings. The objective of this study was to explore the intra-urban variations of geographical accessibility to PHC services in relation to census based socio-demographic factors. Geographically weighted regression (GWR), a local spatial regression technique, was applied to estimate the regression parameters at a local scale in two urban areas: Toronto, Ontario and Calgary, Alberta. The regression analysis was performed using two different methods: 1) by means of a single regression model for both cities together using a regional dummy variable (i.e. 'Multi-City Model'), and 2) using separate models for each city.

Data and Study Area

This research investigates intra-urban spatial patterns in two Canadian cities (census subdivisions "CSDs"): Toronto and Calgary (for locator map, see Figure 5-1). The City of Toronto is the

central part of the largest metropolitan area in Canada (the Greater Toronto Area (GTA)), with a

population of 2.62 million in 2011. The city of Calgary is the third-largest municipality in

Canada and the largest city in Western Canada with a population of 1.10 million. Both cities

have distinct characteristics; for example, population changes from 1996 to 2011 (Toronto =

9.6%; and Calgary = 42.7%), and population density in 2011 (Toronto = 4149.5 and Calgary =

1329 persons per square kilometre)(Statistics Canada, 2007b). Recent developments in the field

of health and urban geography have drawn attention to the need for intra-urban distribution of

health care resources (such as family physicians) with respect to population health care needs.

Health care need can be identified through a number of different methods, including tendency to

seek regular care (Aday & Andersen, 1974). There are a number of benefits associated with

having regular care by a family physician including prevention and treatment of common

diseases and injuries; basic emergency services; referrals to and coordination with other levels of

care, such as hospital and specialist care; primary mental health care, healthy child development,

primary maternity care, rehabilitation services, etc. (Health Canada, 2006; Minister of Health,

2011). It has been reported that 78.8% of the total population (75.6% male; and 82.2% female)

age 12 and over in Calgary census metropolitan areas (CMAs) and 90.3% of the total population

in Toronto (87.3% male; and 93.2% female) have a regular family physician[18]. In this research,

we focused on the spatial distribution of primary health care resources in relation to population

health care needs. An accessibility score that characterizes the ratio of population to PHC

services is used as the dependent variable. A brief description of this dependent variable is as

follows:

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[18] Statistics Canada. 2013. Health Profile. Statistics Canada Catalogue No. 82-228-XWE. Ottawa. Released April 15, 2013.
http://www12.statcan.gc.ca/health-sante/82-228/index.cfm?Lang=E

Our accessibility score is a local form of the physician-to- population ratio. In order to calculate the accessibility score, a GIS-based Three-Step Floating Catchment Area (3SFCA) method was used, which is a local measure of geographical (potential) accessibility to health care resources in urban settings (Bell, et al., 2013; Bissonnette, et al., 2012). There are two spatial layers required to apply the 3SFCA method: 1) population at the smallest possible geographic scale (such as Dissemination Areas (DAs) or Dissemination Blocks (DBs) in Canada, Statistical Area Level 1 (SA1)[19] or Mesh Blocks[20] in Australia, Census Blocks (CB) or Block Groups (BG) in USA[21]), and 2) geographic locations of health care services/sources (such as locations of family physician clinics, dental services, etc.). In this research, DA centroids were used to represent population settings along with the geocoded locations of PHC services. In the first step of the 3SFCA, a physician-to-population ratio (R1) for each PHC practice location was calculated. For this, the number of family physicians/general practitioners at a particular PHC location was divided by the total population within its 3km road network catchment area (considered an appropriate distance to calculate local accessibility). In the second step, a sum of all R1 ratios (R2) those falls within a 3km road network catchment area from any DA centroid was assigned to a DA centroid. In the 3rd step, locally relevant neighbourhoods, as defined by the local government, are used as the units of analysis to calculate the physician-to-population ratio with a neighbourhood accessibility score being generated by aggregating the Step 2 ratios. For further details on how this variable was calculated, see (Shah, et al., Revise and Resubmit). For a more detailed description of the 3SFCA method, see (Bell, et al., 2013; Bissonnette, et al., 2012; Luo, 2004).

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[19] http://www.abs.gov.au/ausstats/abs@.nsf/0/7CAFD05E79EB6F81CA257801000C64CD
[20] http://www.abs.gov.au/ausstats/abs@.nsf/mf/2074.0
[21] http://www.census.gov/geo/reference/garm.html

The spatial patterns of the 3SFCA accessibility scores for both cities are shown in Figure 5-1, maps b and c. Both city maps are prepared using a quantile (Q) classification scheme with four classes (Q1: less than 0.57 physicians per 1000 people, Q2: 0.58 to 0.87, Q3: 0.88 to 1.43, and Q4: 1.44 to 4.41). Neighbourhoods with higher accessibility scores indicate comparatively better geographic accessibility to PHC services for local residents. Comparatively, the mean accessibility score of Calgary neighbourhoods (1.21 physicians per 1000 people) is higher than those in Toronto (1.05 physicians per 1000 people) as indicated in Table 5-1. In both cities, a typical distribution pattern can be seen (see Figure 5-1b and 1c) where higher scores are clustered in the core urban and downtown neighbourhoods with decreasing accessibility toward the edges of the urban areas. It should be noted that there are some limitations to accessibility estimates that may influence accessibility scores. In the 3SFCA method these include the following: physician selection criteria[22]; the procedure implemented in preparing data for analysis[23]; as well as the geocoding method applied (may carry positional errors) (Goldberg, et al., 2007; Hurley, et al., 2003).

In Canada, census-based socio-demographic characteristics for analyzing health disparity at local scales and to proxy for the determinants of health care needs are increasingly used in health geography (Andersen & Davidson, 2001; Bell & Hayes, 2012; Chateau, et al., 2012; Field, 2000; Matheson, et al., 2012; Pampalon, et al., 2012; PHAC, 2012; Wang & Luo, 2005). For this study, eight census-based socio-demographic variables (i.e., derived from the 2006 Canadian census) were shortlisted based on theoretical significance and data availability (see, Shah, et al., 2014). Table 5-1 below indicates some of the main characteristics of these

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[22] Family Doctors, Family Physicians, General Practitioners, or Non-Specialists
[23] Excluded based on: non-geocodable addresses such as physicians having no address or having Post Office Box (P.O. Box) information only, and physicians practicing outside the municipal boundaries.

explanatory variables (mean, as well as standard deviation (SD)) along with information on how these variables were calculated. Note that all explanatory variables were expressed as percentages with higher values indicating higher health care needs.
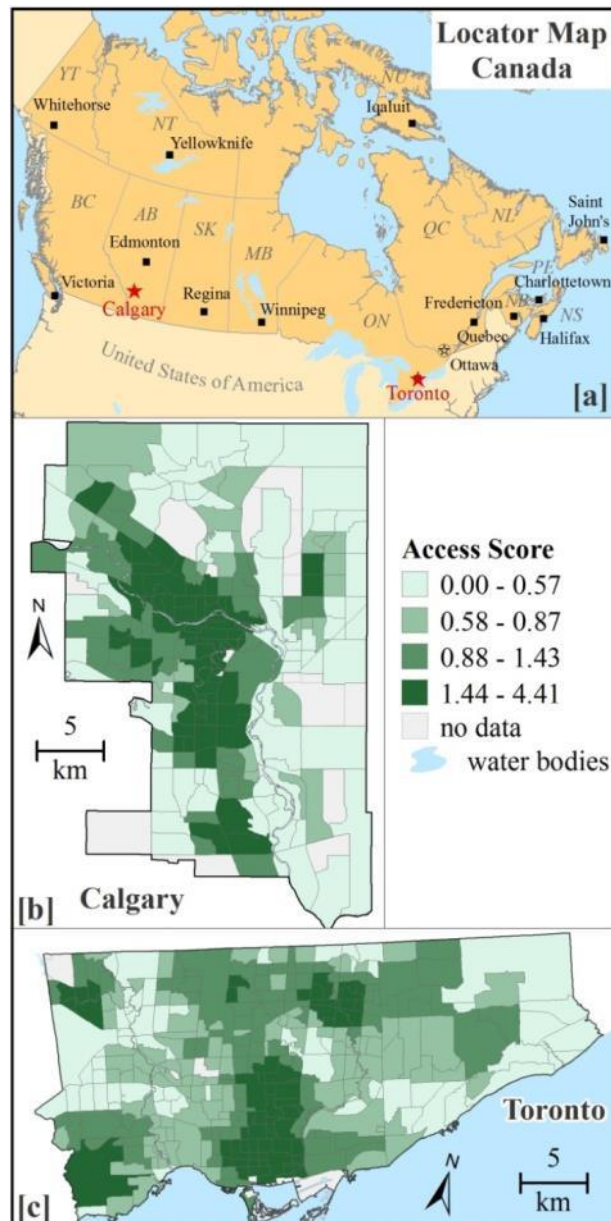

Figure 5-1. Study area map: a) locator map, b) Spatial distribution of the accessibility score (physician-to-1000 population) – Calgary, c) Toronto.

Statistical Analysis and Results

This research used both global and local regression techniques to determine the association between socio-demographic variables and the accessibility score. First, we applied a global regression method, Ordinary Least Squares (OLS), to determine the most suitable model between the accessibility score and the independent variables for both cities together. In this process, to account for regional influence in the regression estimates (cities) we introduced a regional dummy variable (a usual practice in dealing with regional differences (e.g., Chi & Zhu, 2008; Messner & Anselin, 2004; Schmidtner, et al., 2012; Ying, 2003)). Neighbourhoods with no population data were excluded in this analysis. Next, a forward step-wise regression was applied using SPSS software to determine a best OLS regression model by considering adjusted R-square values and coefficient estimates at the 5% significance level. We found that the following variables were associated with accessibility score: percentage of dwellings occupied by the owners (home owners), ppercentage of population 15 years and older without high school certificate, diploma or degree (no high-school), percentage of aboriginal population (aboriginal status), percentage of single parent families (lone parents), percentage of immigrants who came to Canada from 2001-2006 (immigrants), and regional variable (city dummy variable). To determine whether spatial non-stationarity is present or not in the selected multi-city OLS model, we re-ran this model in ArcGIS and found that the relationships modeled are not consistent across space (Koenker statistic = 57.68, df = 6, p<0.001). In order to study how these relationships vary across space as well as to address spatial non-stationarity in the global model, the use of a local spatial regression method appears to be a viable approach (Bagheri, et al., 2009; Chalkias et al., 2013; Gilbert & Chakraborty, 2011; Shoff, Yang, & Matthews, 2012). We

applied the geographically weighted regression (GWR) method to estimate the model

coefficients for each neighbourhood. We used an adaptive spatial kernel as well as the Akaike

Information Criterion (AICc) to determine the optimal number of neighbors (for more detail, see

Fotheringham, et al., 2002, pp. 46-51; Lloyd, 2011, p. 127). The adaptive kernel incorporated

152 neighbors to estimate the multi-city model. The GWR model that estimates regression

coefficients for each neighbourhood indicated a significant improvement in model fit over the

multi-city OLS model. In this model, the AICc values decreased from 1011.8 to 925.1 while

adjusted R-square values increased from 0.354 to 0.500. The results obtained from the multi-city

OLS and multi-city GWR models (coefficient estimates and model performance indicators) are

shown in Table 5-2. In addition, to compare the results of the multi-city GWR model (where data

for both cities were analyzed together), a set of maps for all coefficients, local R-square values

and the condition number are shown in Figure 5-2 (maps a-h).

To understand how the relationships between accessibility score and explanatory

variables change, and to assess the reliability of regression measures in different settings, we

built a separate regression model for Calgary and Toronto (Calgary Model and Toronto Model).

The same statistical procedure as was applied above was used to determine the best OLS models

for Calgary and Toronto, to test spatial non-stationarity, and the GWR model for both cities

separately. The explanatory variables found to be associated with accessibility scores for each

city were as follows: home owners, aboriginal status, and no high-school education in Calgary's

OLS model; and home owners, lone parents, individuals living alone, recent immigrants, and no

high-school education in Toronto's OLS model. It was found that the relationships modeled in

both cities separately are not consistent across space (Koenker statistic = 13.90, df = 3, p =0.003;

Koenker statistic = 36.89, df = 5, p =0.001 in Calgary and Toronto respectively). The GWR

modeling technique with an adaptive spatial kernel was applied and the results in both cases

(Calgary and Toronto models) displayed improvement in model goodness of fit (for Calgary,

AICc values decreased from 455.6 to 386.1 and adjusted R-square increased from 0.450 to

0.670; for Toronto AICc values decreased from 523.7 to 460.6 and adjusted R-square increased

from 0.278 to 0.426). The adaptive kernel incorporated 45 and 207 neighbors to estimate the

Calgary and Toronto models respectively. The results obtained from the OLS and GWR models

(coefficient estimates and model performance indicators) for Calgary and Toronto are given in

Table 5-2 and 3 respectively. The results of GWR models for Calgary and Toronto are mapped

to display the spatial patterns in local coefficient estimates and model fitting as well (Figures 5-3

and 5-4 respectively).

Table 5-1. List of census-based socio-demographic characteristics along-with their descriptive statistics

Variables	Definition	Both Cities		Calgary		Toronto	
		Mean (%)	SD	Mean (%)	SD	Mean (%)	SD
Access score	Physician-to-1000 population ratio at neighbourhood calculated using 3SFCA method (3km network buffers)	1.11	0.80	1.21	0.98	1.05	0.64
Aboriginal	Percentage of aboriginal population	1.24	1.76	2.53	2.20	0.41	0.45
Home Owners	Percent of dwellings occupied by the owners	65.22	22.27	73.19	21.76	60.10	21.08
Lone Parents	Percentage of single parent families	17.33	7.97	14.84	7.85	18.93	7.64
Living alone	Percentage of population 65 years of age and over living alone	3.36	2.91	2.84	3.42	3.69	2.48
No high-school	Percentage of population 15 years and older without high school certificate, diploma or degree	18.62	9.41	17.27	8.11	19.49	10.08
High needs	Percentage of following population groups: children with ages 0-4, seniors with ages above 65, and women with ages 15-44)	41.38	4.87	39.72	5.67	42.45	3.92
Immigrants	Percent of immigrants who came to Canada from 2001-2006	7.78	6.44	5.07	3.98	9.52	7.09
Unemployment	Percentage of population age of 15 years & over in the labour force unemployed	5.89	2.72	3.97	1.75	7.12	2.52

Table 5-2. Results of regression model of accessibility score (Multi-city model): comparative summary of OLS and GWR models.

Variables	OLS coefficients		GWR coefficients							
	β	SE	Mean	SD	Min	Q1	Median	Q3	Max	Range
Intercept	3.85***	0.181	2.901	1.414	0.295	1.421	3.324	3.923	5.538	5.243
Home Owners	-0.023***	0.002	-0.016	0.012	-0.039	-0.025	-0.019	-0.005	0.004	0.044
Lone Parents	-0.02***	0.005	-0.012	0.012	-0.036	-0.022	-0.013	-0.001	0.012	0.048
Aboriginal	-0.089***	0.022	-0.073	0.060	-0.177	-0.116	-0.085	-0.040	0.139	0.316
Immigrants	-0.019***	0.005	0.001	0.020	-0.050	-0.015	0.006	0.017	0.030	0.080
No High-school	-0.018***	0.004	-0.021	0.014	-0.050	-0.032	-0.021	-0.008	0.015	0.065
Toronto (regional)	-0.453***	0.081								
Multiple R-squared		0.361								0.553
Adjusted R-squared		0.354								0.500
AICc		1022.100								915.500

***p<0.001

Table 5-3. Results of regression model of accessibility score (Calgary model): comparative summary of OLS and GWR models

Variables	OLS coefficients		GWR coefficients							
	β	SE	Mean	SD	Min	Q1	Median	Q3	Max	Range
(Constant)	4.18***	0.234	3.316	1.609	0.029	2.038	2.917	4.421	6.991	6.962
Home Owners	-0.028***	0.003	-0.022	0.013	-0.062	-0.028	-0.018	-0.015	0.001	0.063
No High-school	-0.036***	0.007	-0.005	0.055	-0.127	-0.036	-0.013	0.014	0.134	0.261
Aboriginal	-0.104***	0.029	-0.119	0.103	-0.454	-0.183	-0.084	-0.054	0.092	0.545
Multiple R-squared	0.458									0.753
Adjusted R-squared	0.450									0.672
AICc	455.6									386.1

***$p < 0.001$

Table 5-4. Results of regression model of accessibility score (Toronto model): comparative summary of OLS and GWR models

Variables	OLS coefficients		GWR coefficients							
	β	SE	Mean	SD	Min	Q1	Median	Q3	Max	Range
Intercept	3.08***	0.222	2.51	0.86	0.87	1.75	2.35	3.47	3.81	2.943
Home Owners	-0.018***	0.002	-0.01	0.01	-0.03	-0.02	-0.01	-0.01	0.00	0.026
Lone Parents	-0.021***	0.006	-0.01	0.01	-0.03	-0.02	-0.01	0.00	0.00	0.037
Living Alone	-0.031*	0.013	-0.02	0.01	-0.04	-0.02	-0.02	-0.01	0.00	0.041
Immigrants	-0.015**	0.005	-0.01	0.02	-0.04	-0.03	-0.01	0.01	0.02	0.061
No High-school	-0.015***	0.004	-0.02	0.01	-0.04	-0.02	-0.02	-0.01	-0.01	0.036
Multiple R-squared	0.290									0.471
Adjusted R-squared	0.278									0.426
AICc	523.700									460.600

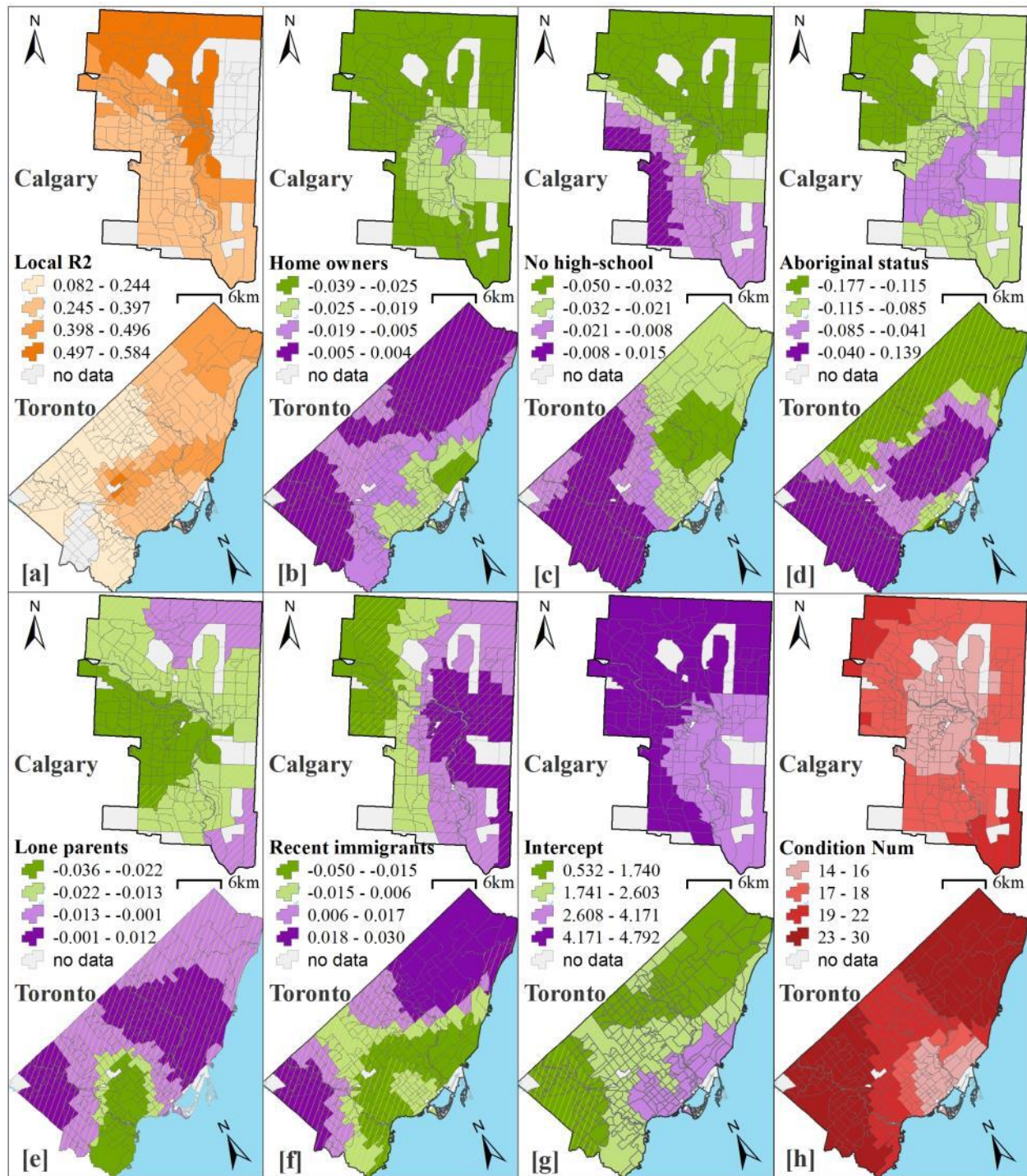***$p < 0.001$; **$p < 0.01$; *$p < 0.05$

Figure 5-2. Multi-city model - the distribution of the GWR results: local R-square (a), coefficient estimates (b-g), and condition number (h). All maps are prepared using quantile classification scheme with four classes and hatch patterns are used to show the pseudo t-values range from -1.96 to 1.96
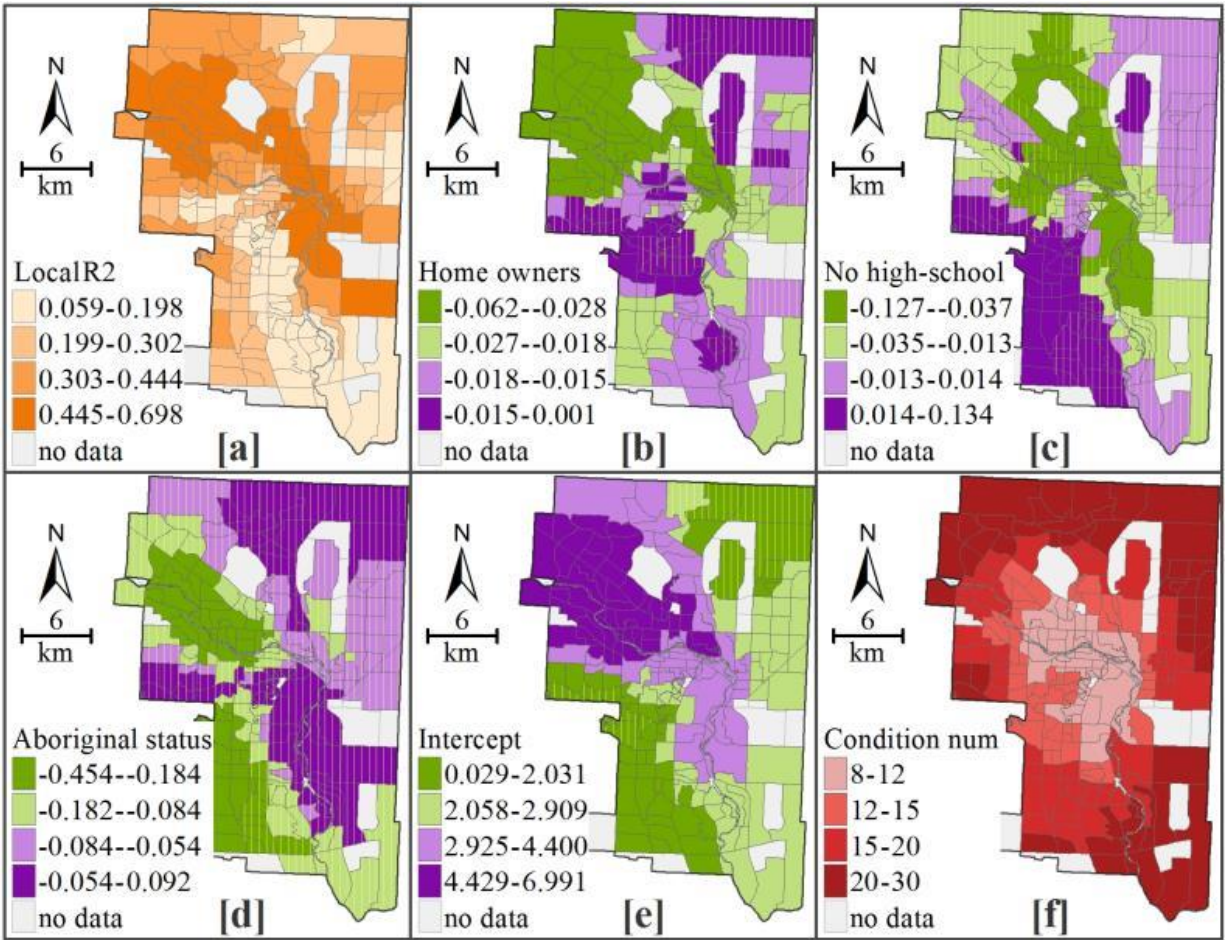
Figure 5-3. Calgary model - the distribution of the GWR results: local R-square (a), coefficient estimates (b-e), and condition number (f). All maps are prepared using quantile classification scheme with four classes and hatch patterns are used to show the t-values range from -1.96 to 1.96
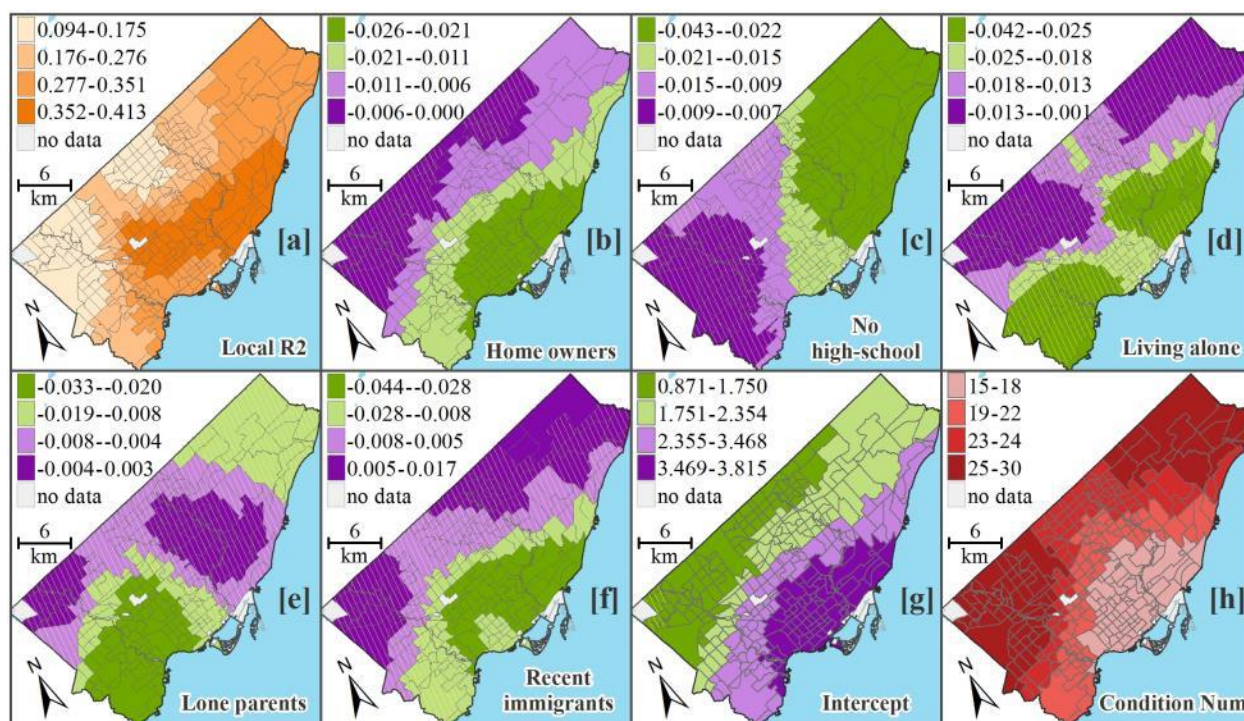
Figure 5-4. Toronto model - the distribution of the GWR results: local R-square (a), coefficient estimates (b-g), and condition number (h). All maps are prepared using quantile classification scheme with four classes and hatch patterns are used to show the t-value

Discussions and Conclusion

This study was designed to explore the intra-urban variations of geographical accessibility to PHC services in relation to various socio-demographic factors. To this end, geographically weighted regression was used to estimate coefficients for each neighbourhood in two urban Canadian settings. The results of the regression analyses that were performed in the two different settings are quite revealing on several fronts.

Based on the multi-city OLS model, a higher proportion of all five significant explanatory variables (as given in Table 5-2) are found associated with smaller accessibility scores (i.e., indicating poor geographic accessibility to PHC services). In this model, Toronto has

a significantly negative influence (-45% on average) for accessibility scores compared to Calgary. Interestingly, a 10 percentage point change in any one of the significant predictors (except for aboriginal status) would result in an approximately 0.2 point change (i.e., 0.2 physicians per 1000 people). In the case of aboriginal status, the same 10 percentage point change would result in an approximately 0.9 point change in accessibility score. GWR estimates local coefficients for the same significant explanatory variables to examine variability across space. The coefficient estimates for the proportion of home owners in comparison to OLS (i.e., -0.023), range from -0.039 to 0.004 with a median of -0.019 (see Table 5-2). This indicates that the relationship between home owners and accessibility is not constant within study areas. What is interesting in the distributions of the local coefficients for this variable is that a stronger magnitude (first quarter, -0.039 to -.025) is observed in the neighbourhoods just outside the downtown area in Calgary whereas in Toronto, such patterns are found within downtown areas (see Figure 5-2b). The coefficient estimates for the proportion of the population aged 15 and over without their high-school certificate in comparison to OLS (i.e., -0.018), range from -0.05 to 0.015 with a median of -0.021 (see Table 5-2); this suggests variation of coefficients across the study area. A stronger magnitude in relation to accessibility score (-0.039 to -0.025 (first quarter)) can be seen in the northeastern and some parts of northwestern Calgary neighbourhoods; and in the case of Toronto, is clustered east of the downtown area (see Figure 5-2c). For the relationship between the proportion of aboriginal population and accessibility score, local coefficients range from -0.177 to -0.115, with interesting patterns observed in Calgary's northeastern neighbourhoods (Figure 5-2d). This indicates a stronger magnitude as compared to the OLS outcome (i.e., -0.089). The distribution of local coefficients for the proportion of lone parent families in relation to accessibility score are shown in Figure 5-2e, and

display interesting patterns in southwestern neighborhoods along with a few downtown

neighbourhoods in Calgary; whereas in Toronto, downtown and some southeastern

neighbourhoods present stronger values (-0.036 to -0.022). The local coefficient estimates for the

proportion of recent immigrants (2001 - 2006) in comparison to OLS estimates (i.e., -0.019),

range from -0.050 to 0.030 with a median of -0.006 (see Table 5-2), indicating that the

relationship of this variable with accessibility score is not constant across space. A stronger

magnitude (0.018 to 0.03) is observed in the Toronto eastern neighbourhoods – specifically in

the Scarborough district (see Figure 5-2f).

Based on individual models, three out of five significant variables (home owners, no

high-school education, and aboriginal status) in the Calgary model and four out of the five

significant predictors (all except for proportion of population aged 65 and over living alone) in

the Toronto model are the same significant predictors as found in the multi-city regression model

(see, Tables 5-3 and 4; Figure 5-3b to 3c and 5-4b to 4f). In both city models, similar to the

multi-city model, a negative association was recognized for all predictors in relation to

accessibility score, however these involved different strength and ranges of the local regression

coefficients. In the Calgary model, a large range of local coefficients is found in all three

predictors that indicate stronger intra-urban variations in relation to accessibility score (see,

Table 5-2 and 3). The Toronto GWR model presents smaller ranges in local coefficients (see,

Table 5-2 and 4).

In all three cases, the GWR model that estimates model coefficients for each

neighbourhood shows a significant improvement in model fitting over the OLS model. These

findings enhance our understanding of geographic accessibility to PHC services (i.e.,

accessibility score). Associations with socio-demographic factors along with the intra-urban

variations found highlight the significance of local spatial regression methods in disaggregating relationships at a local scale. These findings also suggest that a more careful modeling approach is required when analysing data with spatial effects. The findings of this study have a number of policy implications for improving geographic accessibility to PHC services with a focus on urban areas. The 3SFCA accessibility score should be measured on a regular basis to observe changes in the distributions of PHC services in association with socio-demographic characteristics. This study maps the local regression parameters and identifies hot-spots where more PHC resources are required in relation to population health care needs; enabling better data to be available to policy makers and city planners while designing programs to support, facilitate, and guide physicians in practice site identification. Future research should focus on how different units of analysis predict distribution of health care services in the context of modifiable social factors at a local scale.

CHAPTER 6: FIFTH MANUSCRIPT

ASSESSMENT OF CHOICE OF UNITS OF ANALYSIS FOR STUDYING ASSOCIATIONS BETWEEN GEOGRAPHIC ACCESSIBILITY TO PHC SERVICES AND SOCIO-DEMOGRAPHIC FACTORS

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TS conceived and designed the study with LA and SB, assembled input data, analyzed and interpreted the data, and wrote the manuscript.

Chapter 6 presents a comparison between two geographical areal units for studying intra-urban variations in two Canadian urban areas.

CHAPTER 6
ASSESSMENT OF CHOICE OF UNITS OF ANALYSIS FOR STUDYING ASSOCIATIONS BETWEEN GEOGRAPHIC ACCESSIBILITY TO PHC SERVICES AND SOCIO-DEMOGRAPHIC FACTORS

Abstract

The aim of this investigation is to assess the choice of geographical areal units for studying associations between geographic accessibility to primary health care (PHC) services and socio-demographic factors in a Canadian urban context. To achieve this, an accessibility score determined by physician-to-population ratios was calculated at both locally defined neighbourhood and census tract levels in two Canadian cities. The influences of units of analysis on accessibility score were analyzed empirically and a combination of global and local regression models (i.e., OLS and GWR) were applied to both types of units. Regression results demonstrate that the statistical modeling outcomes can be influenced by using different units of analysis which emphasize the use of units of analysis that are pertinent to policy and planning purposes.

Keywords: health geography, MAUP, GWR, units of analysis.

Background and Relevance

In large urban areas, geographic areal units that characterize suburban communities play an important role in the process of localization of health care resources with respect to population needs. In geographical studies, analytical and statistical results can be influenced by the geographical scale and zoning scheme (i.e., the modifiable areal unit problem "MAUP") used to

delineate suburban communities. In recent years, considerable progress has been made in geographic accessibility research in addressing conceptual and methodological issues (for example Bell, et al., 2013; Luo & Whippo, 2012; McGrail, 2012; McLafferty, 2003; Wang, 2012); however, at local scales, for example suburban communities, further investigations are required to address the problems that arise with respect to the geographic areal units used to analyze the distribution of healthcare resources according to population needs. Generally, the modifiable areal unit problem (MAUP) can be categorized based on the contributing spatial aggregation factors which can modify analytical and statistical results: 1) scale effect, related to the number of areal units used (Bell, et al., 2013; Kwan & Weber, 2008; Schuurman, Bell, Dunn, & Oliver, 2007; Smiley et al., 2010), and 2) zonation effect, referring to the choice of boundaries or aggregation (Flowerdew, et al., 2008; Stafford, et al., 2008). This research investigates whether the associations between geographic accessibility to PHC services and socio-demographic characteristics vary depending on the use of different areal units for analysis.

Methods and Data

This study is conducted in two Canadian cities: Toronto and Calgary (Figure 6-1). To investigate MAUP effects, we selected two commonly used areal units of analysis in Canadian urban research: Neighbourhoods (NHs) and Census Tracts (CTs). 2006 census data were obtained at both dissemination area (DA) and Census tract (CT) levels; the DA data was used to prepare the neighbourhood figures. MAUP effects can be either scale- or zone-based in nature; the units of analysis for our research present a scale effect in Toronto (Population mean: NH=7839 and CT=4747) and a zonation effect in Calgary (Population mean: NH=4837 and CT=5313) (Table

6-1). A local form of the physician-to-population ratio (i.e., accessibility score) was used as the

dependent variable. In order to calculate the accessibility score, a GIS-based Three-Step Floating

Catchment Area method (3SFCA) was applied (Aspen, Shah, Wilson, & Bell, 2012; Bell, et al.,

2013; Bissonnette, et al., 2012). The spatial patterns of the 3SFCA accessibility scores for both

cities were mapped using a manual classification scheme (for Neighbourhood, see Figure 6-1a

(Calgary) and 1b (Toronto); for Census Tract, see Figure 6-1c (Calgary) and 1d (Toronto)). Units

with higher accessibility scores indicate comparatively better access to health care resources for

local residents.

Table 6-1. Descriptive statistics – 2006 Population Census

Statistics	Toronto		Calgary	
	Neighbourhood	Census Tract	Neighbourhood	Census Tract
Count (n)*	318 (325)	527 (531)	204 (223)	186 (186)
Population**	2,492,815	2,501,540	986,770	988,165
Mean	7,839	4,747	4,837	5,313
Median	5,273	4,640	3,863	4,873
Std. Deviation	8,415	1,850	3,607	2,749
Range	69,865	22,570	17,580	20,635
Minimum	325	155	300	310
Maximum	70,190	22,725	17,880	20,945

* Neighbourhood counts: non-zero counts (total counts)
**NH population is derived from DA level datasets

In preparing the socio-demographic variables from 2006 census data, eight variables

were shortlisted following consideration of the following studies: (Andersen & Davidson, 2001;

Bell & Hayes, 2012; Chateau, et al., 2012; Field, 2000; Matheson, et al., 2012; Pampalon, et al.,

2012; PHAC, 2012; Wang & Luo, 2005), in addition to an assessment of data availability. Table

6-2 indicates some of the key characteristics of these variables. Note that all of the explanatory variables were expressed as percentages and higher values indicate higher health care needs. Units with no population data were excluded in this analysis. The DA data were used to prepare the neighbourhood variables. This research was performed by first determining an OLS regression model using a forward step-wise approach in SPSS (IBM Corp, 2011). Next, to explore whether the regression coefficients vary across space, we applied a GWR method with an adaptive spatial kernel in ArcGIS (ESRI, 2012). Further, to detect the presence of spatial autocorrelation in the regression residuals, we calculated the Moran's Index (MI) with a queen contiguity spatial weight matrix. Maps were prepared using a quantile classification scheme with four classes.

Results

The results obtained from the OLS regression analysis of accessibility score can be compared in Table 6-3. Comparisons between Neighbourhood and Census tract areal units for both Toronto and Calgary cities based on GWR models are shown in Tables 6-4 and 6-5, and Figures 6-2 and 4 respectively. The spatial distributions of significant predictors in both Toronto and Calgary urban areas (by Neighbourhood and Census Tract) are presented in Figures 6-3 and 6-5 respectively. It is noted that physician and population data that lay outside the municipal boundaries were not considered in the estimation of accessibility scores, or in the modeling process, which could influence the results near the edge of each city.
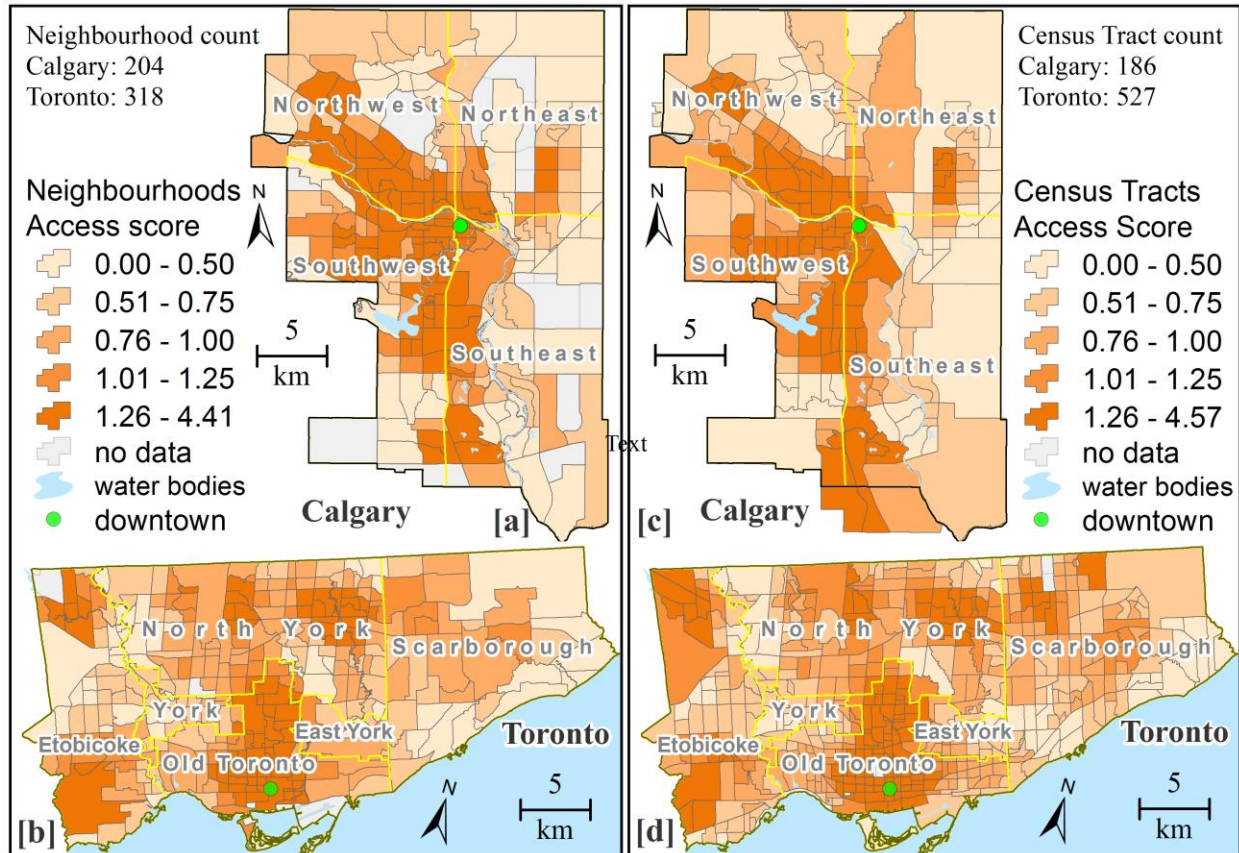
Figure 6-1. Neighbourhood accessibility score - Calgary (a), and Toronto (b), and Census Tract accessibility score - Calgary (c), and Toronto (d)

Note: Both set of maps (Neighbourhood and Census Tract) are prepared using a manual classification scheme with five classes.

Table 6-2. Descriptive Statistics: Mean (Standard deviation 'SD')

Variables	Toronto		Calgary	
	Neighbourhood (n=318)	Census Tract (n=527)	Neighbourhood (n=204)	Census Tract (n=186)
Access Score	1.05 (0.64)	1.05 (0.66)	1.21 (0.98)	1.17 (0.92)
Percent of Population with High Needs	42.4 (4.03)	42.35 (4.03)	39.72 (5.67)	38.81 (4.41)
Percent of Home Owners	60.17 (21.09)	57.4 (23.18)	73.19 (21.76)	73.77 (19.96)
Percent of Lone Parents	18.94 (7.64)	19.91 (7.56)	14.84 (7.85)	15.75 (6.03)
Percent of Aboriginal Population	0.41 (0.46)	0.55 (0.6)	2.53 (2.2)	2.59 (1.82)
Percent of 65+ Living Alone	3.68 (2.47)	3.61 (2.38)	2.84 (3.42)	2.72 (2.87)
Percent of Recent Immigrants	9.5 (7.09)	9.97 (7.65)	5.07 (3.98)	5.32 (3.59)
Percent of 15+ less than High-school education	19.48 (10.06)	20.46 (9.71)	17.27 (8.11)	18.85 (8.09)
Unemployment rate	7.11 (2.52)	7.57 (2.76)	3.97 (1.75)	4.23 (1.29)

To assess MAUP effects and variability across space, we compared the measures of fit (Adjusted R-squared), the number of significant variables found, coefficient estimates, and local coefficients for the predictors. Disparity in our results was observed with respect to the areal unit utilized in both cases (Tables 6-2 and 6-3). In both cities, the NH OLS models performed better over the CT models (Adjusted R-squared for Toronto, NH=0.281 > 0.239=CT; for Calgary, NH=0.450 > 0.443=CT). In Toronto, five variables in the NH model (in comparison to four in the CT model) were found associated with accessibility score; whereas in Calgary, three variables (two common and one different) were found for both the NH and CT models. In all four models, predictors were found to be negatively associated with accessibility score, with the exception of the Living Alone variable in the Calgary CT model. All coefficient estimates for the Toronto NH model were comparatively stronger than in the Toronto CT model (except No High-

school Education). The two common predictors in the Calgary models indicated stronger coefficient estimates for Home Owners in the NH model and No High-school Education in the CT model. Furthermore, our Moran's Index results point towards the presence of spatial autocorrelation in the residuals for the NH and CT models in both cities (Calgary, NH=0.601 < 0.729=CT; Toronto, NH=0.415 < 0.456=CT).

A comparison of adjusted R-squared values from our GWR analysis indicates better performance for the CT model in Toronto (NH=0.425 < 0.571=CT) and better performance for the NH model in Calgary (NH=0.669 > 0.523=CT). The GWR method associates better model fit with increased variance and non-stationarity as reported by the coefficients analyzed. Lone Parents in Toronto, as well as the No High-school and Home Owners variables in both cities follow the adjusted R-squared pattern mentioned above. An example of this can be seen in the No High-school Education variable for the Calgary NH model (table 6-5). Variation in coefficient was from -0.005 to 0.133 for NH, and -0.048 to 0.061 for CT. Spatial non-stationarity is observed in the NH model by a switch from negative to positive values from the Median (-0.013) to the 75th percentile (0.013). This is in contrast to the observed mean (-0.048), as well as the corresponding result for the OLS model (-0.036). These results can be visualized in Figure 6-3, where we see the Southwestern area of Calgary with a high concentration of values in the 0.013 – 0.133 range. Our Moran's Index results point towards improved spatial autocorrelation in the NH models for both cities (Calgary, NH=0.542 < 0.597=CT; Toronto, NH=0.252 < 0.311=CT).

Table 6-3. Results of OLS regression models

Variables	Toronto		Calgary	
	NH	CT	NH	CT
Constant	3.09***	2.43***	4.18***	3.51***
Home Owners	-0.018***	-0.011***	-0.028***	-0.022***
Lone Parents	-0.022***	-0.015**		
Recent Immigrants	-0.015**	-0.009*		
No High-school	-0.015***	-0.018***	-0.036***	-0.045***
Living Alone	-0.030*			0.054**
Aboriginal Status			-0.104***	
Adj. R-squared	0.281	0.239	0.450	0.443
AICc	525.9	912.9	455.6	393.3
Moran's Index (residuals)	0.601***	0.729***	0.415***	0.456***

***p<0.001; **p<0.01; *p<0.05

Table 6-4. Results of GWR models – Toronto and Calgary

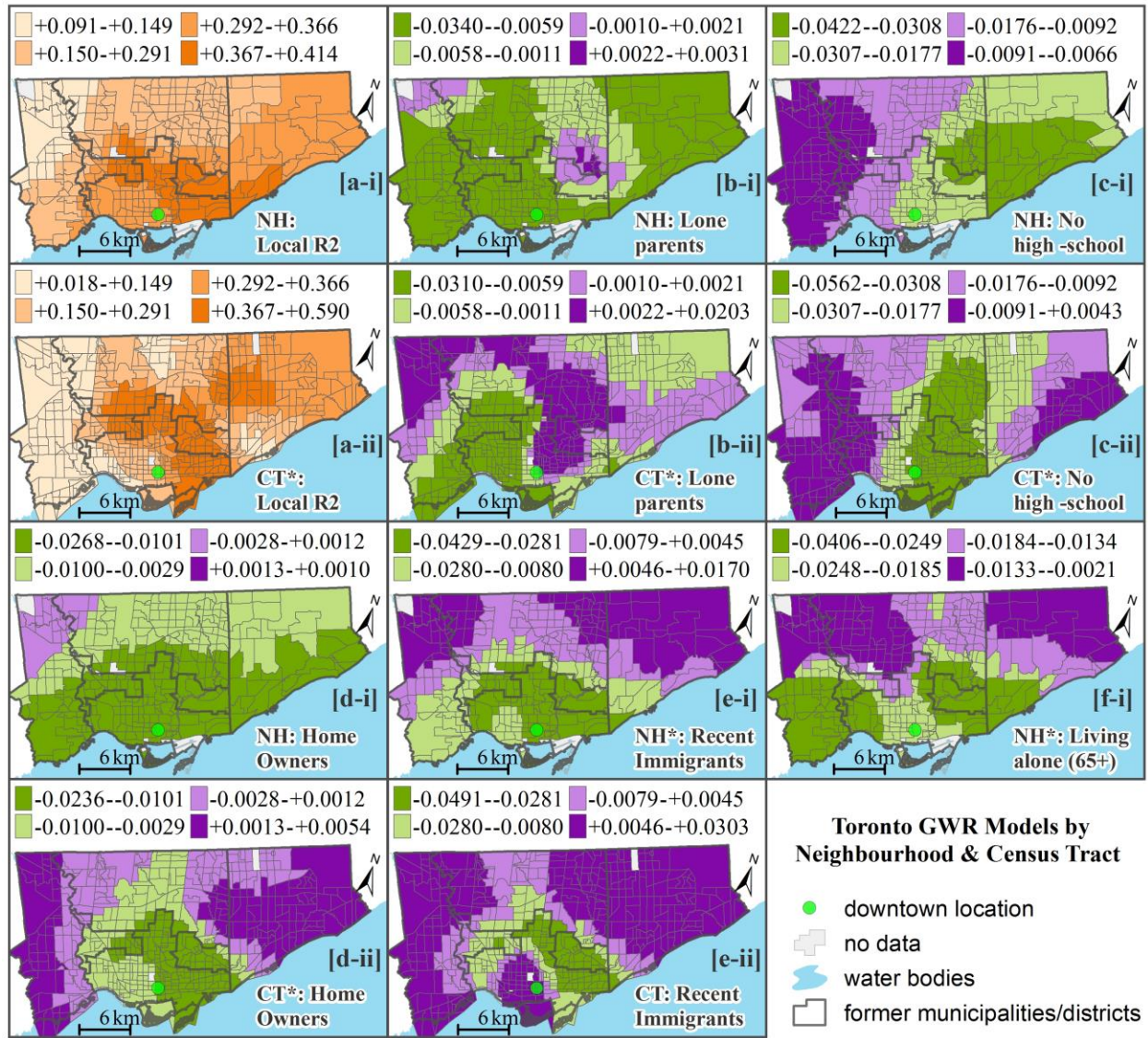| GWR Models	Toronto		Calgary	
	NH	CT	NH	CT
Neighbors	208	187	46	75
Adj. R-squared	0.425	0.571	0.669	0.523
AICc	464.1	629.9	386.5	376.7
Moran's Index (residuals)	0.542***	0.597***	0.252***	0.311***

***p<0.001

Figure 6-2. Results of Toronto GWR model by Neighbourhood (i) and Census Tract (ii). Note that in case of CT model, the variable "Living Alone 65+" is not a significant predictor (for more information, see table 6-3).
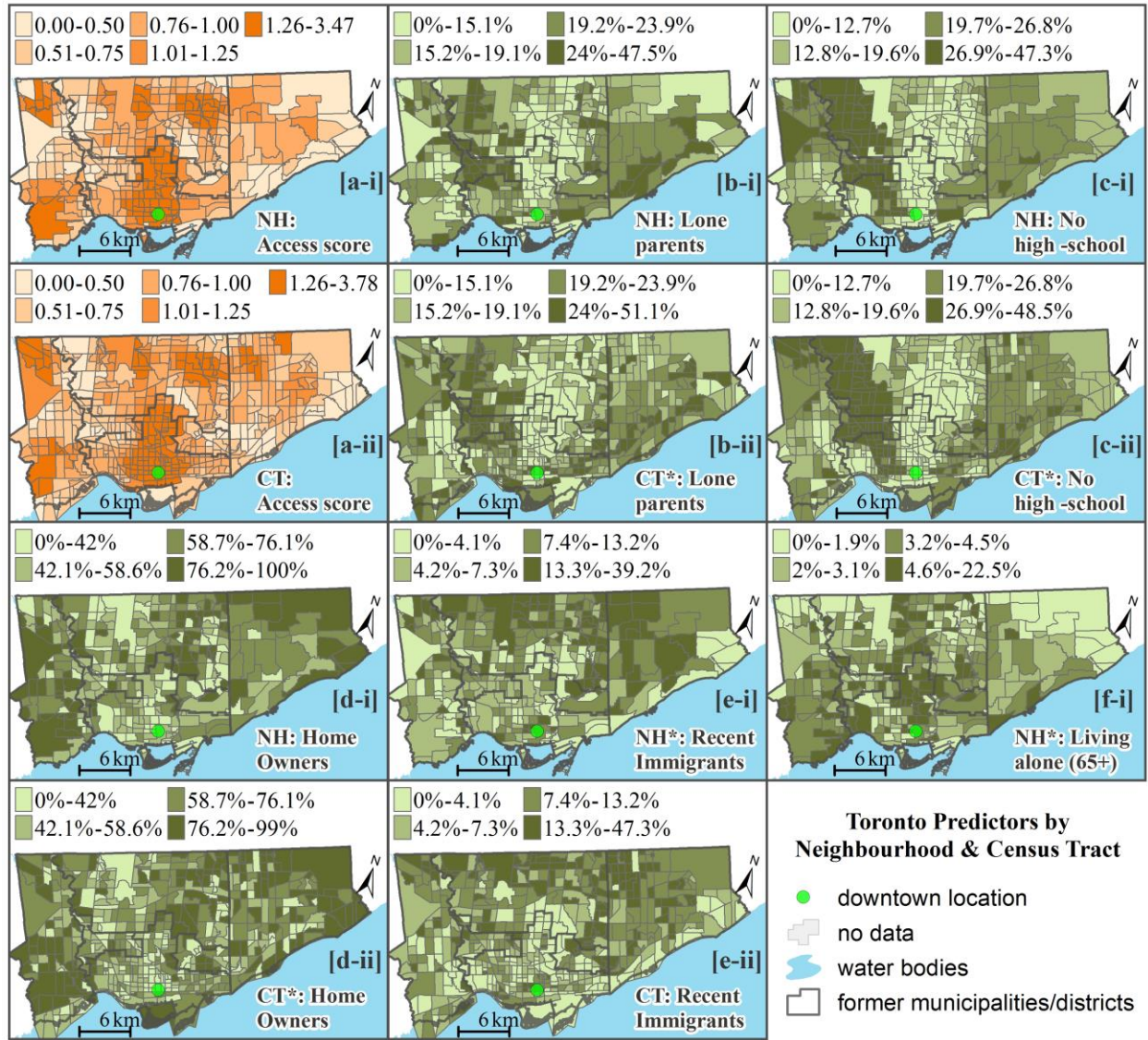Note: * stands for quantile classification scheme used

Figure 6-3. Distributions of significant predictors in Toronto by Neighbourhood (i) and Census Tract (ii). Note that in case of CT model, the variable "Living Alone 65+" is not a significant predictor (for more information, see table 6-3).
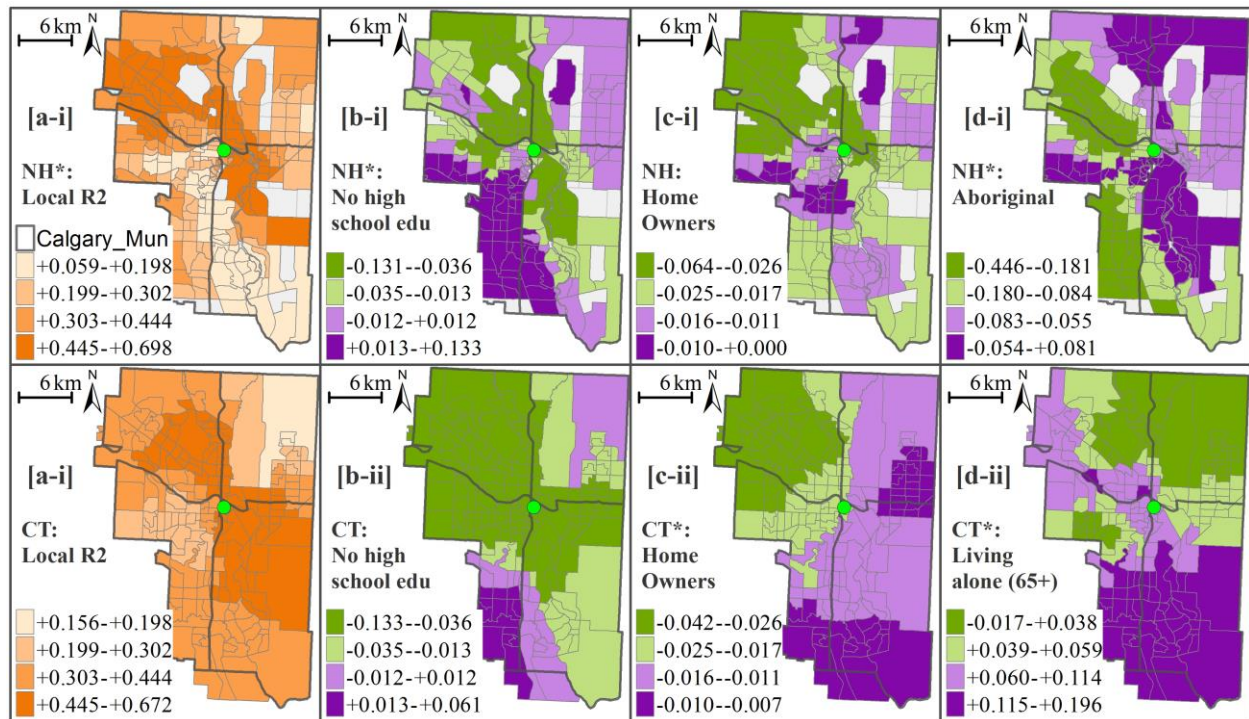
Figure 6-4. Results of Calgary GWR model by Neighbourhood (i) and Census Tract (ii)
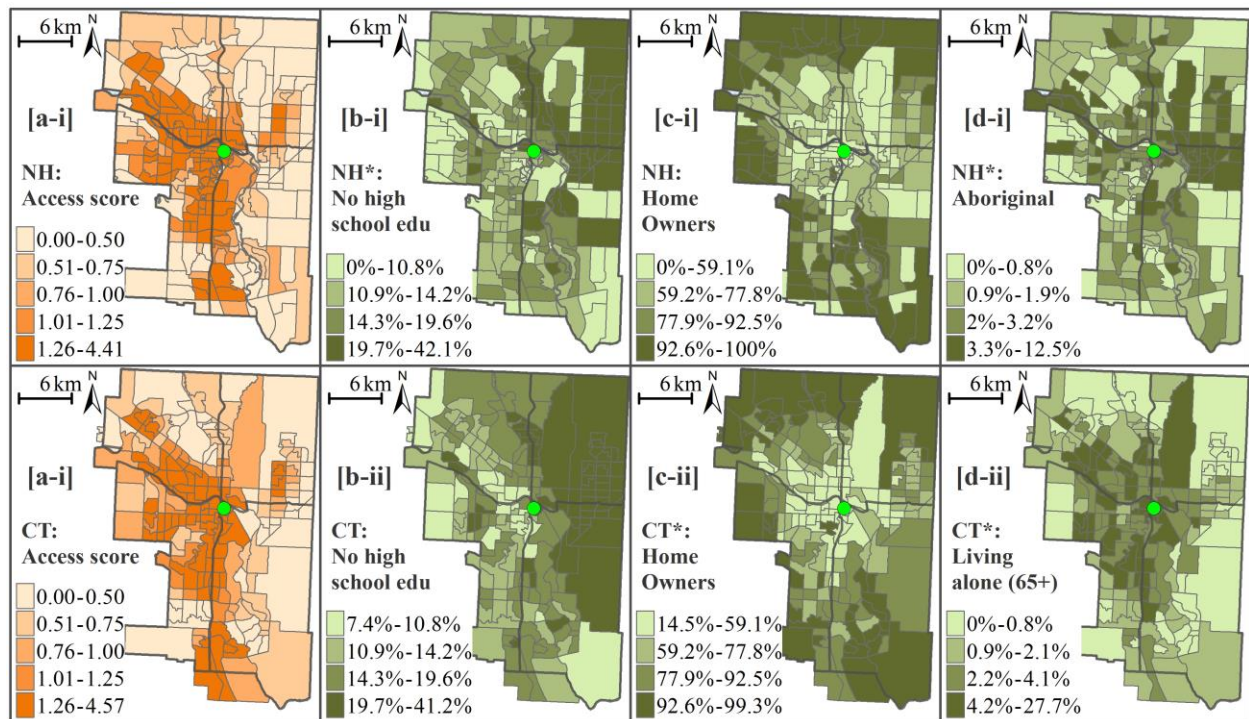Note: * stands for quantile classification scheme used

Figure 6-5. Distributions of significant predictors in Calgary by Neighbourhood (i) and Census Tract (ii)
Note: * stands for quantile classification scheme used

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Table 6-5. Results of GWR models – descriptive statistics

Items	City	Unit	Mean	Min	25th	Median	75th	Max
LocalR2	Toronto	NH	0.265	0.091	0.173	0.276	0.353	0.414
		CT	0.273	0.018	0.149	0.291	0.366	0.590
	Calgary	NH	0.328	0.057	0.201	0.304	0.449	0.694
		CT	0.409	0.156	0.343	0.421	0.473	0.672
Intercept	Toronto	NH	2.534	0.856	1.798	2.429	3.457	3.814
		CT	1.729	0.170	0.900	1.401	2.615	3.705
	Calgary	NH	3.342	0.110	2.061	2.882	4.437	6.968
		CT	3.246	0.301	2.254	3.322	4.268	5.921
Lone Parents	Toronto	NH	-0.012	-0.034	-0.020	-0.009	-0.004	0.003
		CT	-0.003	-0.031	-0.006	-0.001	0.002	0.020
	Calgary	NH						
		CT						
No High-school	Toronto	NH	-0.017	-0.042	-0.022	-0.015	-0.009	-0.007
		CT	-0.020	-0.056	-0.031	-0.018	-0.009	0.004
	Calgary	NH	-0.005	-0.131	-0.035	-0.013	0.013	0.133
		CT	-0.048	-0.133	-0.075	-0.045	-0.024	0.061
Home Owners	Toronto	NH	-0.013	-0.027	-0.021	-0.012	-0.007	0.000
		CT	-0.005	-0.024	-0.010	-0.003	0.001	0.005
	Calgary	NH	-0.023	-0.064	-0.028	-0.018	-0.015	0.000
		CT	-0.019	-0.042	-0.026	-0.017	-0.011	-0.007
Recent Immigrants (Toronto)/ Aboriginal Status (Calgary)	Toronto	NH	-0.011	-0.043	-0.028	-0.008	0.004	0.017
		CT	0.001	-0.049	-0.015	0.006	0.019	0.030
	Calgary	NH	-0.120	-0.446	-0.181	-0.084	-0.055	0.081
		CT						
Living Alone	Toronto	NH	-0.019	-0.041	-0.025	-0.019	-0.013	-0.002
		CT						
	Calgary	NH						
		CT	0.080	-0.017	0.038	0.059	0.114	0.196

Discussion and Conclusions

MAUP effects were observed in using Neighbourhood versus Census Tract boundaries with respect to population health care needs (accessibility) in Toronto and Calgary. In OLS regression, the use of Neighbourhood models indicated better representation of the data set over Census Tract models for both cities. A local form of regression (GWR) indicated that a Census Tract model performed better over a Neighbourhood model in Toronto, whereas the reverse was true in Calgary.

The results highlight some of the interesting patterns and relationships of spatial accessibility to PHC services with population health care needs across both cities. First of all, the percentage of population 15 years and older without a high school certificate, diploma or degree, which may be related to service awareness, is found negatively associated with accessibility scores in all four models. In Toronto, NHs having higher proportions of less educated population (i.e., 19.7% and above; see, Figure 6-3 panel c) are located in the East York and southern part of Scarborough, they tend to show show a strong positive association with accessibility scores (Figure 6-2, panel c) in comparison to the CT model. Interesting results can also be seen in Calgary, NHs along the boundary between northeast and southeast Calgary have a less educated population (see, Figure 6-5 panel b) and show a weak (and positive) relationships to accessibility to primary care whereas the CT model predicts a stronger relationships in these areas (see, Figure 6-4, panel b). Such areas could be unnoticed by health and city planners who are interested in developing programs to support physicians in practice site identification in order to address the population health care needs using inappropriate areal units. Similar patterns can be seen in the case of home ownership. Scarborough NHs in Toronto and most of the NHs in Southeast and

Southwest Calgary present strong negative association with accessibility scores, which is not present in the CT models (see Figures 6-2 and 6-3, panel d).

Numerous studies have reported that lone parent families and recent immigrant populations have comparatively poorer health status and face more difficulties accessing primary health care (Asanin & Wilson, 2008; Benzeval, 1998; Dunn & Dyck, 2000; Popay & Jones, 1990; Sanmartin & Ross, 2006; Weitoft, Hjern, Haglund, & Rosén, 2003; Westin & Westerling, 2006; Young, Cunningham, & Buist, 2005). The higher proportion of lone parents and recent immigrants (2001-2006) in both units (NH and CT) are associated with low accessibility scores in Toronto and likely represent a lower likelihood of finding a PHC location near their place of residence. Variations in the intra-urban distributions of local coefficients for these variables using NHs and CTs provide some insights into planning challenges. For example, in the case of lone parents, the southern part of the Scarborough and a majority of North York neighbourhoods suggest strong negative associations whereas the same areas based on CTs, present poor or no relationships with accessibility (see, Figures 6-2 and 6-3 and panel b).

It is unlikely that these results can be easily generalized for different cities, socio-economic variables, or dependent variables. Rather, it is important to understand the implications of our analysis towards areal unit choice, and to be aware of the difficulty in discerning which is the most appropriate without performing a proper analysis using both. In summary, using inappropriate areal units can result in poor interpretations of healthcare needs. This research demonstrates how the influences of units of analysis on accessibility score can change the statistical outcomes for suburban geographic areal units, which highlights the importance of choosing an appropriate neighbourhood definition that are pertinent to policy and planning purposes. As well, this research contributes to the existing body of literature on geographical

accessibility to PHC services with a focus on large urban areas. The outcome of this study using

city defined neigbhourhoods and census tracts can also be leveraged by health and city planners

who are interested in developing programs to support, facilitate, and guide physicians in practice

site identification in order to address the population health care needs.

CHAPTER 7: GENERAL DISCUSSION

GEOGRAPHICAL ACCESS TO PRIMARY HEALTH CARE SERVICES ACROSS
CANADIAN CITIES: A GENERAL DISCUSSION

Chapter 7 concludes the dissertation by summarizing the key findings and conclusions presented

in the preceding sections. The policy implication and recommendations for future research are

also discussed in this chapter.

CHAPTER 7
GEOGRAPHICAL ACCESS TO PRIMARY HEALTH CARE SERVICES ACROSS CANADIAN CITIES: A GENERAL DISCUSSION

Introduction

The primary objective of this study was to examine the variation in spatial accessibility to permanently located primary health care (PHC) services in the Canadian urban settings. For this, the following 14 urban areas across Canada were examined: Victoria and Vancouver, British Columbia; Calgary and Edmonton, Alberta; Saskatoon, Saskatchewan; Winnipeg, Manitoba; Hamilton, and Toronto, Ontario; Montréal and Québec, Quebec; Halifax, Nova Scotia; St. John's, Newfoundland; Saint John, New Brunswick; and Ottawa–Gatineau, Ontario and Quebec. The study sought to address the following key issues related to geographic accessibility to primary health care (PHC) services: first, to measure the spatial accessibility to and of primary health care services (i.e., accessibility score) using a GIS based three-step floating catchment areas (3SFCA) method in the selected 14 urban areas across Canada; second, based on accessibility score calculated, identify under-served (or poorly served) neighbourhoods (or population) in the study areas; and finally, with the use of GIS and spatial statistical tools, to analyze the patterns of spatial accessibility to PHC services between the neighbourhoods and among the urban areas by exploring the relationships of accessibility with census-based socio-demographic characteristics. To understand the possible effect of choice of areal unit definition /operationalization and the relationship between the geographical accessibility to PHC services and socio-demographic characteristics at local scales, further spatial analyses were performed using Geographically Weighted Regression (GWR) method.

This study has found considerable spatial variations in potential geographical accessibility to PHC services within and across Canadian urban areas and indicates the existence of clusters of poorly served neighbourhoods in all 14 urban areas. This study showed the benefit of using the 3SFCA method over simpler approaches in urban areas by providing similar results of City level physician-to-population ratios with the advantage of intra-urban measurements. The present study confirms previous findings (Bell, et al., 2013; Bell, et al., 2012; Bissonnette, et al., 2012) by providing additional evidence which suggests the 3SFCA method is an important addition in the field of public health in getting measures of geographical accessibility to health care at both urban and intra-urban levels by applying a single method.

In urban context, this study found that socio-demographic characteristics that include prevalence of low-income (LICO), population without high-school education, population with high needs for healthcare, and dwellings in need of major repairs are associated with geographical accessibility to PHC services. This is the largest study so far documenting a comparison of low accessibility scores with higher proportions of different predictors that reveal variations in geographical accessibility to PHC services both within an urban area and across Canada. In addition, spatial statistical modeling and subsequent use of the local Moran's I technique allowed identification of those neighbourhoods presenting a mismatch of accessibility scores and population health care needs for services.

The findings from this study contribute to the health geography literature in several ways. Findings based on the local spatial regression (i.e., GWR model that estimates model coefficients for each neighbourhood) demonstrated a significant improvement in model fit over the OLS model, enhancing our understanding of geographic accessibility to PHC services. This study highlights the significance of local spatial regression methods in disaggregating

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relationships at a local scale; this suggests that a more careful modeling approach is required when analysing data with spatial effects. This research also demonstrated the importance of choosing an appropriate neighbourhood definition for suburban geographic units by exploring disparity in modifiable areal unit problem (MAUP) effects using Neighbourhood versus Census Tract boundaries with respect to population health care needs.

The geographic location of health care facilities plays an important role in most of the GIS-based methods measuring potential spatial accessibility. To address the issues related to geographic locations of social facilities particularly PHC services, this study applied integrated geocoding procedures for increasing geocoding match rates with reduced positional uncertainty. This study has successfully demonstrated how results of geocoding methods that are generally used to get geographic coordinates can be improved without compromising the positional accuracy. Additionally, integrated geocoding procedures for increasing match rates with reduced positional uncertainty is suggested. This hybrid geocoding approach incorporates weaknesses and strengths of different geocoding methods that incorporate different reference datasets in the course of merging geocoding results. It is important to mention here that other approaches exist for merging results such as taking the average of different geocoding services, using merging to identify "outlier" locations that may have inaccurate data or using one set as a check on the others, etc. that needs to be tested.

Overall, neighbourhoods with poor accessibility scores (i.e., physician-to-1000 population / geographical accessibility to PHC services) are found in major urban settings across Canada that have further disadvantages in relation to population health care needs. The 3SFCA accessibility score, in comparison with traditional physician-to-population ratio, is a consistent and useful measure across Canadian urban areas; this result demonstrates the advantage of using

the 3SFCA method to calculate geographic accessibility. Local spatial patterns of accessibility scores identified with both global and local spatial statistical techniques are useful to narrow down the target areas for interventions.

Limitations

In this section, a number of possible research limitations regarding the present study are discussed along with the suggestions how such limitations could be overcome in future work. The physician information used in measuring the geographical accessibility, as discussed in the previous chapters, was gathered from nine provincial databases (College of physicians and surgeons) across Canada. Lack of data compatibility and different nomenclature used for physicians providing primary health care services may affect the physicians selection from these provincial data sources. This is also mentioned in a recently published report that "the counts of physicians from these various sources may not agree due to the inclusion and exclusion criteria applied by each source, and the timing of their data collection" (Canadian Institute for Health Information, 2012, p. 109). Only those physicians who fall in the category of General Practitioners, Family Doctors, Family Physicians or Non-Specialists are considered for this research. This may underestimate the accessibility to PHC services. A national level Physician and clinic database (or directory) connected with provincial databases would be helpful in overcoming such data compatibility and incomplete information matters.

In this research, PHC practice locations and DA centroids that are used to represent the health care supply and demand sites, respectively, play an important role in measuring geographical healthcare accessibility at a local scale. A set of geographic coordinates for PHC

practice sites, which are mostly located in non-residential areas (e.g., institutional and commercial areas including shopping malls), are generated by applying an integrated geocoding procedure to overcome the lower geocoding match rates for such areas (McKendry, et al., 2006; McLafferty, et al., 2012; Zandbergen, 2008). Physicians having invalid or incomplete addresses such as 202 physicians with Post Office Box (P.O. Box) information and 68 without postal addresses that could not be geocoded accurately (Goldberg, et al., 2007; Hurley, et al., 2003) were removed. In health geography, the centre of a geographical areal unit is determined by using different methods that include population-weighted centroids, mean centre (centroid or centre of gravity), median centre etc. To represent demand sites in the 3SFCA method, the DA centroids along-with population data from the 2006 and 2011 Canadian censuses was used. It is assumed that size of dissemination areas, especially in urban areas, are small and all methods will produce similar results. In multivariate spatial analysis, the neighbourhood socio-demographic variables were prepared using DA level data. Results need to be interpreted carefully because the data aggregation process involved and miscalculation at some places where DA don't respect neighbourhood boundaries. One of the possible remedies would be to ask Statistic Canada to customize census data by neighbourhood.

Urban settings are the focus on this research and the selection of each urban area was made by considering the municipal administrative division (or census subdivision), and availability of city-defined neighbourhoods (that are used as the unit of analysis). The DA centroids and PHC practices that lay outside the selected municipal boundaries were not involved in the estimation of accessibility scores or in the modeling process, which could influence the results near the edge of each city. The nature of these edge effects is sensitive to the type of neighboring municipality (such as whether it is urban or rural).

One limitation of the 2SFCA and 3SFCA methods is its reliance on a single buffer size, and the assumption that access is uniform within that buffer (Luo & Qi, 2009). An alternative could be deriving variable catchment size (Luo & Whippo, 2012). This is only possible when target population or catchment area is already known such as the US Department of Health and Human Services (DHHS) follows a "population to full-time-equivalent primary care physician ratio of at least 3,500: 1" as thresholds (DHHS, 2013; Luo & Qi, 2009). Despite these limitations, the study makes a number of important contributions.

Policy Implication and Conclusion

The findings of this study suggest several courses of action for improving geographical accessibility to primary health care services in Canadian urban areas. It is important to measure geographic accessibility to health services, particularly PHC services, on a regular basis to observe changes in poorly served areas, distribution of health care services, and its relationships with population health care needs. Moreover, in identification of poorly served pockets of the urban fabric, the relationship of geographic accessibility to health care services with social-demographic factors could play an important role that needs to be established on a priority basis. It is suggested that such information on geographic accessibility to PHC services should be shared with physicians; particularly those who are looking to start new practice, those who are in training/newly graduated, or those who wish to change their practice locations. A variety of communication modes that include web-mapping, mobile mapping, etc. can be used in sharing such information with the right people.

Information on geographic accessibility would be very helpful for policymakers, researchers, city planners, community workers, and those residents who need services. This information can also be leveraged by health and city planners who are interested in developing programs to support, facilitate, and guide physicians in practice site identification. Moreover, a similar process can be repeated for measuring the 3SFCA accessibility score for dental, HIV, and rehabilitation, and mental health care services to assess the specific healthcare needs.

A national physician workforce databank that manages both physician and clinic profiles in a standardized relational database, well connected with provincial and regional databases would be helpful in mapping service locations, measuring geographical distributions, and accessibility to PHC services at local scales. Including information on a clinic's working hours, practice size, and practice setting (e.g., solo practice, group practice, or interprofessional practice) along with information on a physician's work settings, work hours, hours by location, mode of payment, language skills, status on accepting patients etc., should be a part of this physician workforce databank. Such information across the continuum of national to municipal levels would be beneficial in exploring different aspects of geographic accessibility and its links with contextual and socio-demographic factors.

One of the important contributions of this study concerns methods that can improve geocoding results. Where positional accuracy matters, use of an integrated (or hybrid) geocoding approach over the Postal Code Conversion File (PCCF), which is mostly used in research conducted by national/ provincial health partners in Canada (for example, Matheson et al., 2006; Mechanda & Puderer, 2007; Pong & Pitblado, 2005), would be a positive initiative.

The choice of geographical areal units for studying distribution of health care resources with respect to population needs matters particularly in urban settings, which highlights neighbourhood effects on health. This study, by involving various spatial statistics, offered the opportunity to identify geographical areal units (i.e., local neighbourhoods) suitable to research purposes.

In spite what is often stated about health care availability (or physician-to-population ratio) in large urban settings, variations in the distributions of and potential geographical accessibility to PHC services between the neighbourhoods and among the urban areas exists. The benefits of investigating potential geographical accessibility to PHC services in urban settings would be helpful in improving the health care supply and distribution with respect to population health care needs and advance our understanding of access to PHC services at a local scale as well.

Recommendation for Future Research

The focus of this study was to examine the potential geographical access to and of PHC services in the urban areas across Canada, identify under-served population at neighborhoods, and to analyze the patterns of spatial accessibility to PHC services between the neighbourhoods and among the urban settings. This study is based on the notion that all physicians are equal in terms of service output. To make meaningful policy strategies and initiatives it would be interesting to extend the findings of this study using Full-Time Equivalent (FTE) measurements (British Columbia Medical Association, 2011; Pong & Pitblado, 2005, p. 55), information on physicians

accepting patients, etc. Further research is needed to better understand the potential edge effects

that may influence the analysis.

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Geocoding for public health research: Empirical comparison of two geocoding services applied to Canadian cities

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The process of geocoding, particularly the street address matching process, is a commonly used technique to obtain locational information for public health research. In health care accessibility research, geocoded locations of health care providers are an essential element for measuring potential access to health care. Our objective is to compare the geocoding match rates and positional variation of two geocoding procedures by using street network and postal code datasets to geocode primary health care services in 14 cities. The first procedure uses a manually built geocoding service using DMTI Spatial (DMTI) reference datasets while the second employs an online geocoding service provided as a built-in tool in ArcGIS, with ESRI Tele Atlas reference datasets. Results for Tele Atlas postal code and DMTI multiple enhanced postal codes (MEP) reference datasets produce much higher match rates (99.4%; 98.0% respectively) than street reference datsasets; while results of Tele Atlas street dataset produce better match rates (96.5%) than the DMTI street dataset (90.0%). Geocoding methods using Tele Atlas and DMTI Street datasets produce more accurate locations than postal code and MEP reference datasets. Empirical comparison of the geocoding results based on manually built and online geocoding services highlight the need for integrated geocoding procedures for increasing match rates with reduced positional uncertainty.

Keywords: Urban geocoding, primary health care, health geography, automated geocoding, positional uncertainty

Le géocodage dans la recherche en santé publique : une comparaison empirique de deux services de géocodage utilisés dans les villes canadiennes

Le processus de géocodage, notamment le processus d'appariement des adresses civiques, est une technique couramment employée en vue d'obtenir des renseignements de localisation dans la recherche en santé publique. Dans les travaux de recherche portant sur l'accessibilité aux services de santé, les localisations géocodées des fournisseurs de services de soins de santé constituent des éléments de première importance pour estimer le niveau d'accès aux soins de santé. L'objectif poursuivi est d'établir, à partir de bases de données sur le réseau routier et les codes postaux, une comparaison entre les taux d'appariement par géocodage et la variation de positionnement de deux opérations de géocodage afin de procéder à la localisation par géocodage des services de soins de santé primaires dans 14 villes. La première opération se réalise par un service de géocodage configuré manuellement en utilisant les ensembles de données de référence de DMTI Spatial. La seconde opération se sert d'un service de géocodage en ligne fourni en tant qu'outil intégré du logiciel ArcGIS, avec les ensembles de données de référence de Tele Atlas de l'ESRI. Les

Investigating impacts of positional error on potential health care accessibility

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ABSTRACT

Accessibility to health services at the local or community level is an effective approach to measuring health care delivery in various constituencies in Canada and the United States. GIS and spatial methods play an important role in measuring potential access to health services. The Three-Step Floating Catchment Area (3SFCA) method is a GIS based procedure developed to calculate potential (spatial) accessibility as a ratio of primary health care (PHC) providers to the surrounding population in urban settings. This method uses PHC provider locations in textual/address format supplied by local, regional, or national health authorities. An automated geocoding procedure is normally used to convert such addresses to a pair of geographic coordinates. The accuracy of geocoding depends on the type of reference data and the amount of value-added effort applied. This research investigates the success and accuracy of six geocoding methods as well as how geocoding error affects the 3SFCA method. ArcGIS software is used for geocoding and spatial accessibility estimation. Results will focus on two implications of geocoding: (1) the success and accuracy of different automated and value-added geocoding; and (2) the implications of these geocoding methods for GIS-based methods that generalise results based on location data.

1. Introduction

Accessibility to health services at local and community scales is an important metric for measuring health care delivery in Canada and the United States. The concept of access to health care is multifaceted; it builds links between populations at risk (clients) and the delivery system (service providers) which vary across both space and place (Penchansky and Thomas, 1981). In measuring potential access to health services Geographical Information Systems (GIS) and spatial methods provide powerful analytic tools. The Three-Step Floating Catchment Area (3SFCA) method is a GIS-based procedure developed by Bell (forthcoming) to calculate potential (spatial) accessibility at the neighbourhood level as a ratio of primary health care (PHC) providers to population in urban settings.

Like other GIS based methods, measuring potential (spatial) access to health care requires locations of Primary Health Care (PHC) providers in global absolute geographic coordinates (Latitude/Longitude, Universal Transverse Mercator (UTM), etc.) and population information associated with enumeration areas (census areas or local neighbourhoods) (Bell et al., forthcoming; Luo, 2004; Luo and Wang, 2003; McGrail and Humphreys, 2009; Paez et al., 2010; Schuurman and BÉRubÉ, 2010). In Canada, census based population data is gathered by Statistics Canada every five years and is available at a variety of enumeration levels. One such enumeration unit, and the unit used in

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Neighbourhoods and potential access to health care: The role of spatial and aspatial factors

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ABSTRACT

The availability of, and access to, primary health care is one neighbourhood characteristic that has the potential to impact health thus representing an important area of focus for neighbourhood-health research. This research examines neighbourhood access to primary health care in the city of Mississauga, Ontario, Canada. A modification of the Two Step Floating Catchment Area method is used to measure multiple spatial and aspatial (social) dimensions of potential access to primary health care in natural neighbourhoods of Mississauga. The analysis reveals that neighbourhood-level potential access to primary care is dependant on spatial and aspatial dimensions of access selected for examination. The results also show that potential accessibility is reduced for linguistic minorities as well as for recent immigrant populations who appear, on the surface, to have better access to walk-in clinics than dedicated physicians. The research results reinforce the importance of focusing on intra-urban variations in access to care and demonstrate the utility of a new approach for studying neighbourhood impacts that better represents spatial variations in health care access and demand.

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1. Introduction

The study of neighbourhoods and their effects on the health and well-being of residents has quite a lengthy history in the social sciences (e.g., sociology and geography) (Garner and Raudenbush, 1991; Mullins, 1973; Russ-Eft, 1979; Herbert, 1976; Johnston, 1976; Smith, 1980). More recently, interest has grown in other fields, most notably in public health and epidemiology (Kawachi and Berkman, 2003; Diez Roux, 2001; Schempf et al., 2011). Despite the growth in neighbourhood-health studies there is no single definition of what constitutes a neighbourhood. Rather, it seems that definitions of neighbourhood and methods for operationalizing neighbourhood and measuring neighbourhood-effects appear to be strongly linked to both the research question and the type of data (i.e., secondary or primary) available for analysis. That said, within the neighbourhood-health field, there are some key commonalities in conceptualizations of neighbourhoods (see Weiss et al., 2007). For example, Galster (2001, p. 28) in critiquing early work that employed ecological definitions (e.g., a physical area with specific boundaries) or a mix of ecological and social definitions (a geographically bounded area in which residents interact socially), stresses the importance of also accounting for features of the local environment in defining neighbourhoods: "the bundle of spatially based attributes, associated with clusters of residences, sometimes in conjunction with other land uses." Similarly, (Lebel et al., 2007) define neighbourhood as "a place characterised by a specific collection of spatially-based features that can be found at a specific geographic scale.''

In employing these and other similar definitions, studies have shown a strong relationship between neighbourhood of residence and a number of health outcomes including low birth weight and infant mortality (Buka et al., 2003; O'campo et al., 1997; Szwarcwald et al., 2002), self-rated health (Wen et al., 2006; Patel et al., 2003; Kawachi et al., 1999), cardiovascular disease and other chronic conditions including coronary heart disease (Sundquist et al., 2004; Diez-Roux et al., 1997), stress, and depression (Matheson et al., 2006; Boardman et al., 2001). In addition, neighbourhood contextual characteristics have also been shown to influence health related behaviours, such as smoking (Frohlich et al., 2002; Duncan et al., 1999; Kleinschmidt et al., 1995), alcohol consumption (Stockdale et al., 2007; Pollack et al., 2005; Duncan et al., 2002), diet (Morland et al., 2002; Lee and Cubbin, 2002; Ecob and Macintyre, 2000), and physical activity (Harrison et al., 2007; Fisher et al., 2004; Giles-Corti and Donovan, 2002).

In searching for the links among neighbourhoods, health status, and health behaviours, research has concentrated on the social and physical characteristics of neighbourhood environments. In doing so, it has been shown that neighbourhood-level characteristics have an impact on health above and beyond the characteristics of individuals. In particular, research has pointed

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Access to Primary Health Care: Does Neighborhood of Residence Matter?

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Neighborhood social and physical contexts have the ability to impact health and health behaviors of residents. One neighborhood characteristic that remains underexamined in the research is access to health care resources. This research examines potential (geographical) access to primary health care in the city of Mississauga, Ontario, Canada. A modification of the two-step floating catchment area method that better suits the study of locally relevant natural neighborhood units is presented. Potential access to health care is measured in each of Mississauga's neighborhoods considering several spatial and aspatial (i.e., social) characteristics of the population and of physicians, including the raw abundance of physicians, languages spoken by physicians and patients, and whether physicians are accepting new patients. Neighborhood-level results are compared to census tracts. The results of this analysis reveal that potential access significantly differs between neighborhoods for all spatial and aspatial dimensions of access. Accessibility is considerably reduced for linguistic minorities and for those who might not have a dedicated family physician as compared to the general population. This research contributes to the existing body of literature on neighborhoods and health by demonstrating the utility of an alternative methodology for developing a more comprehensive understanding of access to health care within natural geographical neighborhoods. *Key Words: access to health care, geographic information systems, neighborhoods, primary health care.*

社区的社会和物理环境有影响居民的健康和健康行为的能力。我们对社区的一个特点，即其对医疗资源的获取性，仍然缺少调查研究。本研究探讨加拿大安大略省密西沙加市的居民对初级卫生保健的潜在的（地理的）获取性。说明了一个对更适合研究局地相关的自然社区单位的两步浮动集水区法的改进。衡量在每个密西沙加市社区，潜在的对卫生保健的获取性。考虑一些空间和非空间（如，社会）的人口和医生的特征，包括医生的原充足度，医生和病人所说的语言，和医生是否接受新患者。对邻里级的人口普查道进行了比较。这一分析结果表明，潜在的访问度在社区之间，在访问的所有的空间和非空间尺寸的维度，存在显著的不同。访问度对语言上的少数群体和那些可能没有一个专门的家庭医生的群体，与一般人群相比大大减少。这项研究通过展示使用一个替代方法，该方法发展我们对自然地理社区内的医疗保健的获取性的更全面的理解，有助于推进在社区和健康领域的现有文献的贡献。*关键词：医疗保健的获取性，地理信息系统，社区，初级卫生保健。*

Los contextos sociales y físicos del vecindario tienen la capacidad de impactar la salud y a los comportamientos de los residentes relacionados con salud. Una característica vecinal que permanece poco estudiada en investigación es la del acceso a los recursos de atención a la salud. Esta investigación examina el acceso potencial (geográfico) a los servicios de cuidado primario de la salud de la ciudad de Mississauga, Ontario, en Canadá. Se presenta una versión modificada del método flotante de doble paso para un área determinada que mejor se acomoda al estudio de unidades barriales naturales localmente relevantes. El acceso potencial a los servicios de salud se midió en cada barrio de Mississauga tomando en cuenta varias características tanto espaciales como aespaciales (esto es, sociales) de la población y de los médicos, incluyendo la simple abundancia de médicos, idiomas hablados por los médicos y pacientes, y datos sobre si los médicos estaban aceptando nuevos pacientes. Los resultados a nivel de vecindario se comparan con los distritos censales. Los resultados de este análisis revelan que el acceso potencial difiere significativamente entre los vecindarios en todas las dimensiones espaciales y aespaciales del acceso. La accesibilidad se ve reducida considerablemente para las minorías lingüísticas y para quienes podrían no disponer de un médico de familia dedicado en comparación con lo que ocurre en la población general. Esta investigación contribuye a enriquecer el cuerpo de literatura actual sobre vecindarios y salud al demostrar la utilidad de una metodología alternativa para desarrollar un mejor entendimiento del acceso a los servicios de cuidado de la salud en vecindarios geográficos naturales. *Palabras clave: acceso al servicio de atención de la salud, sistemas de información geográfica, vecindarios, cuidado básico de salud.*

Does Location Matter: Effects of Distance & Practice Size on Consumer Preferences for Seeking Primary Healthcare

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ABSTRACT

This article examines distance to healthcare services and physician practice size as factors influencing consumer preference and choice when seeking primary healthcare (PHC) in an urban setting. Data from a multipurpose telephone survey for the Canadian city of Saskatoon, Saskatchewan was analyzed. Using network analyst in ArcGIS and information drawn from this survey, distances to respondents' regular family physicians were compared against distances to the location where healthcare was alternatively received. Statistical analysis demonstrated preferences for larger, more local practices at the expense of continuity of care. These findings suggest erratic utilization of healthcare services that could lead to further healthcare access issues. This paper contributes to a growing body of work that recognizes the complexity of access to healthcare; most importantly it suggests that lower neighbourhood level access can result in health care decisions that might reduce continuity of care.

Categories and Subject Descriptors

H.2.8 [Models and Principles]: Database Applications – *Spatial databases and GIS*

General Terms

Measurement, Documentation, and Human Factors

Keywords

GIS, access to healthcare, continuity of care, neighbourhood-level access, distance variables, practice size variables

1. INTRODUCTION

Primary healthcare services, in the form of pharmacists, family physicians, as well as walk-in, community, and after-hours clinics all provide gateways to secondary healthcare providers that are important for the treatment, diagnosis, and prevention of illness [1]. Access to primary care is vital in decreasing the probability of acute illness [2], thus relieving congestion in secondary healthcare facilities. It is clear that a deficiency in access to primary care can result in negative health outcomes, higher disease rates, and poor healthcare utilization [3]. Accessibility and availability of primary care services are thus essential health determinants in any society. The Canadian healthcare system provides Canadians with medically necessary services free at the point of delivery [4]. While the Canadian healthcare system is often held up as a model of universal health care, research in recent years has shown a lack of satisfaction with accessibility [5]. In addition, in 2003 approximately 15% of Canadians reported difficulties accessing routine care, and nearly 23% reported problems accessing immediate care according to the CCHS (Canadian Community Health Survey) [6]. It should be noted that a decline in accessibility has been reported since the 1990s [7]. Healthcare accessibility, the right and ability for an individual to act as a healthcare consumer, can be defined on several levels related to predisposing, enabling, and need factors that are recognized as key determinants of access [8]; as a result, this ongoing deficiency in access could be attributed to a number of factors including urban development and expansion, distribution of healthcare facilities, and socioeconomic and demographic variables. As well, demand for PHC services has increased in Canada due to an aging population, rising patient expectations, a shift in focus from hospital care to community care, an increase in pressure to contain costs, and a slow supply of physicians [9]. It is important to investigate causes of this reported decline in accessibility if solutions are to be found. From a geographic perspective, distance and distribution of healthcare facilities presents an interesting dynamic in regards to accessibility and associated problems.

Exploring the Intra-Urban Variations in the Relationship among Geographic Accessibility to PHC Services and Socio-demographic Factors

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ABSTRACT
In this study, we investigate the intra-urban variations in the relationships among various socio-demographic factors and geographical accessibility to primary health care (PHC) services using a local regression model. Geographic accessibility to PHC services is calculated at a local scale for two Canadian urban centers (Calgary, AB and Toronto, ON) using a three-step floating catchment area (3SFCA) method. Socio-demographic factors were derived from 2006 Canada census data. The regression analysis was performed using two different methods: 1) a single regression model for both cities together, using a regional dummy variable, and 2) separate models for each city. A similar modeling procedure was applied for both methods: first, a best Ordinary Least Squares (OLS) regression model was determined using a forward step-wise approach in SPSS software. Next, to test the spatial non-stationarity in the regression residuals, the best OLS model was repeated in ArcGIS. Further, to explore whether or not regression coefficients vary across space, we applied the geographically weighted regression (GWR) method with an adaptive spatial kernel. The GWR results exhibit the intra-urban variations in the relationships between socio-demographic factors and the accessibility score. A comparison of the GWR models demonstrates the benefit of local spatial regression in disaggregating the relationships between socio-demographic variables and the geographical accessibility to PHC services at a local scale; however, our results suggest that a more careful modeling approach is required when analysing the data with spatial effects.

Categories and Subject Descriptors
K.4.1 [**Computers and Society**]: Public Policy Issues – *computer-related health issues.*

General Terms
Measurement, Performance, Design, Verification

Keywords

Spatial non-stationarity, geographically weighted regression, urban geography, physician-to-population, geographic accessibility

1. INTRODUCTION
There are many challenges to health care delivery in urban areas. Among them is the relationship between the arrangement of primary health care facilities and the populations they are meant to serve. In this context, geographic accessibility to PHC services in association with health care needs is a critical and relatively unstudied topic. In Canada, access to health care is essential in ensuring all people receive adequate health care as near as possible to their residence [1]. Geographic access to health care in relation to population health needs (or consumers) varies across space [2]. In health geography, the multivariate regression technique is normally used to determine the association of a response variable with explanatory factors; however, with current advancements in GIS, spatial data handling, and spatial statistics, spatial regression methods are increasingly used to address methodological issues as well as the contextual aspects of spatial data analysis [3-12]. The main advantage of spatial regression, in addition to increasing the reliability of regression measures, is to explore the spatial variation between variables. This is typically achieved by focusing on certain spatial effects that normally exist in spatial data. Two types of spatial processes that can affect regression estimates are considered for regression models in geography: spatial autocorrelation and spatial non-stationarity (heterogeneity) [as discussed by 13]. Spatial autocorrelation is related to spatial dependence in regression residuals, and can often result in misleading outcomes for coefficient significance tests. Spatial non-stationarity in spatial data modeling indicates that the variance of residuals is different across the space in question. There is no practical modeling solution to address both spatial effects in a single modeling framework except for the possibility of a 'geographically weighted version of a spatial regression model' [14]. Local models have several comparative advantages over global spatial regression, these include: local regression coefficients, mappable regression parameters, and local hot-spot identification [15]. Furthermore, the process of calibrating local models can accommodate the problem of spatial dependency in regression residuals [14, 15].

In this research, we focus on local spatial regression to model geographical accessibility to PHC services in urban settings. The objective of this study was to explore the intra-urban variations of geographical accessibility to PHC services in relation to census based socio-demographic factors. Geographically weighted regression (GWR), a local spatial regression technique, was

Assessment of Choice of Units of Analysis for Studying Associations between Geographic Accessibility to PHC Services and Socio-demographic Factors

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Abstract

The aim of this investigation is to assess the choice of geographical areal units for studying associations between geographic accessibility to primary health care (PHC) services and socio-demographic factors in a Canadian urban context. To achieve this, an accessibility score determined by physician to population ratios was calculated at both locally defined neighbourhood and census tract levels in two Canadian cities. The influences of units of analysis on accessibility score were analyzed empirically and a combination of global and local regression models (i.e., OLS and GWR) were applied to both types of units. Regression results demonstrate that the statistical modeling outcomes can be influenced by using different units of analysis which emphasize the use of units of analysis that are pertinent to policy and planning purposes.

Keywords: health geography, MAUP, GWR, units of analysis.

Background and Relevance

In large urban areas, geographic areal units that characterize suburban communities play an important role in the process of localization of health care resources with respect to population needs. In geographical studies, analytical and statistical results can be influenced by the geographical scale and zoning scheme (i.e., modifiable areal unit problem 'MAUP') used to delineate suburban communities. In recent years, considerable progress has been made in geographic accessibility research in addressing conceptual and methodological issues (For example S. Bell, Wilson, Bissonette, & Shah, 2012; Luo & Whippo, 2012; McGrail, 2012; Sara L., 2003; Fahui Wang, 2012); however, at a local scale such as suburban communities, more investigations are required to address the problems that arise with respect to the geographic areal units used to analyze the distribution of healthcare resources according to population needs. Generally, the modifiable areal unit problem (MAUP) can be categorized based on the contributing spatial aggregation factors which can modify analytical and statistical results: 1) scale effect, related to the number of areal units used(S. Bell, et al., 2012; Kwan & Weber, 2008; Schuurman, Bell, Dunn, & Oliver, 2007; Smiley et al., 2010), and 2) zonation effect, referring to the choice of boundaries or aggregation (Flowerdew, Manley, & Sabel, 2008; Stafford, Duke-Williams, & Shelton, 2008). This research investigates whether the associations between geographic accessibility to PHC services and socio-demographic characteristics vary in using different areal units for analysis in two Canadian cities.

Study Area and Data

This study is conducted in two Canadian cities: Toronto and Calgary (Figure 1). To investigate the MAUP effects, we selected two commonly used areal units of analysis in Canadian urban

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Research Work

Refereed Journal and Conference proceedings publications

Shah, T. I., Bell, S., & Wilson, K. (2014). Geocoding for Public Health Research: Empirical Comparison of Two Geocoding Services Applied to Canadian Cities. *Canadian Geographer*, n/a-n/a. doi: 10.1111/cag.12091

Shah, T. I., & Bell, S. (2013). *Exploring the Intra-Urban Variations in the Relationship among Geographic Accessibility to PHC Services and Socio-demographic Factors*. Paper presented at the HealthGIS 2013 - Second SIGSPATIAL International Workshop on the use of GIS in Public Health.

Bell, S., Wilson, K., Bissonette, L., & **Shah, T**. (2012). Access to primary health care: does neighbourhood of residence matter? Annals of the Association of American Geographers.

Bell, S., Wilson, K., **Shah, T. I**., Gersher, S., & Elliott, T. (2012). Investigating Impacts of Positional Error on Potential Health Care Accessibility. Spatial and Spatio-temporal Epidemiology, 3(1), 17-29.

Bissonnette, L., Wilson, K., Bell, S., & **Shah, T. I.** (2012). Neighbourhoods and potential access to health care: The role of spatial and aspatial factors. Health & Place, 18(4), 841-853.

Aspen, L., **Shah, T. I.,** Wilson, K., & Bell, S. (2012). Does Location Matter: Effects of Distance and Practice Size on Consumer Preferences for Seeking Primary Healthcare, HealthGIS 2012 - First SIGSPATIAL International Workshop on the use of GIS in Public Health. Redondo Beach, California: ACM SIGSPATIAL.

Shah, T. I., Bell, S., & Ellahi, M. (2011). School mapping in education micro-planning: a case study of Union Council Chak 84/15L, District Khanewal, Pakistan (No. 1911-5814). Saskatoon, SK: University of Saskatchewan.

Almas, A. S., Rahim, C. A., Butt, M. J., & **Shah, T. I**. (2005). Metropolitan growth monitoring and landuse classification using geospatial techniques. Paper presented at the ISPRS Workshop on Service and Application of Spatial Data Infrastructure, Hangzhou, China. , XXXVI-4/W6 277-282. Retrieved from http://www.isprs.org/proceedings/XXXVI/4-W6/papers/277-282%20Amjed%20S.%20Almas-A039.pdf

Bashir, F., & **Ikram, T.** (2003) Implementation of Disease Early Warning System on Malaria. Journal of Medical Sciences 3(3): 227-239
http://scialert.net/qredirect.php?doi=jms.2003.227.239&linkid=pdf

Engler-Stringer, R., **Shah, T. I.,** Bell, S., & Muhajarine, N. (Revise and Resubmit). Geographic Access to Healthy and Unhealthy Food Sources for Children in Neighbourhoods and from Elementary Schools in a Mid-Sized Canadian City. Spatial and Spatio-temporal Epidemiology.

Shah, T. I., Bell, S., & Wilson, K. (Revise and Resubmit). Spatial Accessibility to Healthcare Services: To Identify Under-Served Areas in Canadian Urban Setting. Social science & medicine.

Technical/Survey Reports:
Shahab, S., & **Shah, T. I.** (1999). Tracking tuberculosis using GIS (Geographical Information Systems: In Strengthening TB control at district level; HSA Press Public Health Monograph Series No.2: 25-26, 1999, Islamabad.
UNICEF/WFP/WHO Joint Survey in collaboration with MOH (2006). Health & Nutrition Survey in Earthquake Affected Areas of Pakistan (Survey Report Islamabad). Retrieved from
http://www.who.int/hac/crises/international/pakistan_earthquake/sitrep/Pakistan_nutrition _survey_report_07Feb2006.pdf (as Survey Manager and Trainer)

As Technical Manager / coordinator, I have had an opportunity to conduct an household census with focused on education and out of school children information in four districts of Punjab, Pakistan (that includes instrument design, designing of software for data entry, analysis and reporting, training of master trainers, survey monitoring, setting data cleaning and entry procedures/ guidelines, etc.).

Literacy Management Information System (LitMIS): is a computer-aided system, developed on need-based strategy to facilitate the executive district officers (EDO-Literacy) and other stakeholders in planning and implementation of social sector activities especially for Adult Literacy and Non Formal Basic Education (NFBE). This project was technical funded by JICA under the name of Punjab Literacy Promotion Project (PLPP) and I was the technical Manager/Coordinator for this project.

Atlases (Health and Education): These atlases are published in paper and electronic formats. I was the technical Project Manager to handle the data collection, preparing map templates, developing GIS, and finally coordinate with printing press.
http://www.esri.com/news/arcnews/summer04articles/pakistan-publishes.html

1) Pakistan Health & Population Welfare Facilities Atlas: (District maps, list of Health & Population welfare facilities of Pakistan)

Published in 2003; Volumes: 1; Paper size: A3 (colored)
Published by: Centre for Research on Poverty Reduction and Income Distribution (CRPRID),
Planning Commission of Pakistan. Funded by: UNICEF and UNDP

2) Education and School Atlas of Pakistan: (District maps & list of Educational institutes)
Published in 2003; Volumes: 6; Paper size: A3 (colored)
Published by: Centre for Research on Poverty Reduction and Income Distribution (CRPRID),
Planning Commission of Pakistan. Funded by: UNICEF and UNDP

Unpublished work:

Shah, T. I. (1997). *Remote Sensing Technology and its application to Geological and Land use /
Land cover classification of Islamabad and adjoining areas* (Unpublished master's
thesis). University of the Punjab, Lahore Pakistan

Conference Presentations:

Shah, T. I., & Bell, S. (2013, November). *Exploring the Intra-Urban Variations in the
Relationship among Geographic Accessibility to PHC Services and Socio-demographic Factors*.
Presented at the HealthGIS 2013 - Second SIGSPATIAL International Workshop on the use of
GIS in Public Health, Orlando, US

Engler-Stringer, R., Shah, T. I., Bell, S., & Muhajarine, N. (2013). *Geographical inequalities in
children's access to healthy and less-healthy food sources (Oral presentation)*. Paper presented
at the Moving Public Health Forward: Evidence, Policy, Practice, Ottawa, ON.

Shah, T. I., Bell, S., & Wilson, K. (2011, October). Neighbourhood models to identify MAUP
effects using spatial regression. Presented at the poster session of the GEOMED 2011
conference, Victoria (British Columbia), Canada.

Shah, T. I., & Bell, S. (2010, September). School mapping in education micro- planning: a case
study of union council Chak 84-15l, District Khanewal, Pakistan. Presented at the paper session
of the Annual Meeting of the Prairie Division of the Canadian Association of Geographers,
North Battleford (Saskatchewan), Canada

Shah, T. I., Bell, S., & Wilson, K. (2010, June). Spatial Analysis in primary healthcare: an
application to spatial accessibility in Saskatoon neighbourhoods. Paper session presented at The
Prairie Summit, Regina (Saskatchewan) Canada

Shah, T. I., Imran, M., & Shahab, S. (1999, April). Network analysis for emergency response
planning for ambulance facility. Paper session presented at GIS in New Millennium, Islamabad,
Pakistan

GIS and Computer Skills

GIS & RS Software: ESRI (ArcGIS 10.x, ArcView3.x, Spatial Analyst, 3D Analyst) MapInfo Professional, AutoCAD Map, ER Mapper, UDig, Quantum GIS and EpiInfo2000 GeoDa, IBM SPSS, MS Access, MS Excel, Basic understanding of (SQL database, PostGIS & PostGre SQL)

*GIS related short courses (*completed following ESRI web courses):
- Learning ArcGIS Desktop (For ARCGIS 10) – completion date (December 24, 2010)
- Regression Analysis Using ArcGIS 10.1 – completion date (March 25, 2013)
- Basics of Geographic Coordinate Systems (for ArcGIS 10) – completion date (February 19, 2013)
- Exploring Spatial Patterns-using ArcGIS 10 – completion date (March 08, 2013)
- Turning Data into Information Using ArcGIS 10 – completion date (October 10, 2011)
- Creating Web Applications with ArcGIS – Technical seminar conducted on September 28, 2011 by ESRI, Canada (Location: Regina, Saskatchewan)

Awards
- Dean's Scholarship Research award – Sept 2009-Aug 2012 (from The College of Graduate Studies and Research, University of Saskatchewan, Saskatoon, SK)
- Teacher Scholar Doctoral Fellowship (TSDF) form Sept 2012-Aug 2013 (from The College of Graduate Studies and Research, University of Saskatchewan, Saskatoon, SK)
- 2013 Esri Canada GIS Scholarship (from ESRI, the makers of ArcGIS and related GIS software)
- Graduate Service Fellowship (GSF) for the 2013 fall session – Sept 2013 – Dec 2013 (from Social Sciences Research Laboratories 'SSRL,' University of Saskatchewan)

Services
April 2014 –Present   Reviewer, social science & medicine journal
May 2014 – Present   Abstract reviewer, 7th International Symposium: The Safety & Health in Agricultural & Rural Populations: Global Perspectives (SHARP)

Citizenship
Pakistan and Canada

Membership
Canadian association of geographers