15-MINUTE CITY: ACCESS TO ESSENTIAL SERVICES IN METRO VANCOUVER

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Abstract

This study quantified access to six essential services using the "15-Minute City" concept and the measure of cumulative opportunity in Metro Vancouver. "15-Minute Cities" are suggested to promote multiple health-focused goals such as health equity, active transportation, and sustainable development to improve the well-being of the population. Locations of 3357 Dissemination Area (DA) population-weighted centroids (origins) and healthcare facilities, education centres, greenspace, grocery stores, community centres and public transit stops (destinations) were identified using multiple open data sources. Accessibility was determined by the walking time between each origin-destination pair using a transportation routing engine with two different walking speeds representing people of different ages. Access was then evaluated by population density, municipality, age and a measure of situational deprivation as a proxy for socioeconomic status. Only 22% of DAs in Metro Vancouver had access to all six essential services and were considered "15-Minute City" neighbourhoods in this analysis. These DAs had higher population density, a lower proportion of populations between ages 0 to 14, and the highest proportion in the least situationally deprived category. Greenspace and community centres were the most (99%) and least accessible (36%) essential services within 15 minutes of walking, respectively. This study highlighted access inequity to essential services across Metro Vancouver based on socioeconomic and demographic characteristics. The "15-Minute City" was an innovative framework that was used to quantify disparities in access. This framework can inform decision making and improve resource allocation to support sustainable development in Metro Vancouver of more complete and walkable neighbourhoods.

Lay Summary

This study evaluated whether people in Metro Vancouver had access to six essential services: healthcare facilities, education centres, greenspace, grocery stores, community centres and public transit stops within fifteen minutes of walking from their place of residence. Only 22% of Metro Vancouver neighborhoods had access to all six services within 15 minutes of walking, with inequalities of access varying by municipality, socioeconomic status and age distribution, based in part on differences in population density. This results and tools of this study can help policymakers assess current levels of access and inequity to prioritize improvements in neighborhood planning and the delivery of services. Improved access equity in access to basic services can help promote healthy behaviours such as walking to daily activities and social cohesion, to improve community health and sustainability.

Preface

The thesis work described here was part of the Pathways to Equitable Healthy Cities Global Partnership project.

This thesis is the work of Mu Li and was conducted under the supervision of Drs. Michael Brauer and Kate Weinberger of The University of British Columbia, and Meghan Winters of the Simon Fraser University.

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List of Abbreviations

BC	British Columbia
BMI	Body Mass Index
CIMD	Canadian Index of Multiple Deprivation
DA	Dissemination Area
DMTI EPOI	DMTI Enhanced Points of Interest
NAICS	North American Industry Classification System
NDVI	Normalized Difference Vegetation Index
OSM	OpenStreetMap
R5R	Rapid Realistic Routing with R5
SES	Socioeconomic Status
SIC	Standard Industrial Classification
WHO	World Health Organization
UN	United Nations
UNSDG	United Nations Sustainability Development Goals

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Chapter 1: Introduction

This thesis was developed to address the benefits and current lack of research on equitable access to essential services in Metro Vancouver. This introductory chapter begins by describing the need for healthy cities based in the context of increasing global urbanization. Indicators of healthy cities and influences on urban planning are described to highlight the need to understand access to essential services as a component of a healthy city. Equitable access to essential services and the "15-Minute City" perspective are also introduced, followed by the rationale and objectives of this thesis.

1.1 Healthy Cities

More than four billion people currently live in urban areas globally. It was projected that more than two-thirds of the global population will live in urban areas by 2050, which is approximately seven billion people (Ritchie & Roser, 2018). The trend of urbanization had been occurring for the past few centuries and is still accelerating in many countries around the world including Canada. Currently, 82.2% of the Canadian population lives in urban centres. Population growth in rural areas had lagged urban areas with the rural population growth rate was fifteen times slower than that of urban regions between 2016 and 2021. The most recent 2021 Statistics Canada Census data showed that urban municipalities grew as much as 10.6%, which was higher than the national growth average of 5.2% (Government of Canada, 2022a). Urbanization can bring numerous health improvements and economic opportunities to people; however, it can also pose several urban health challenges that reinforce stress on populations and natural environments (Sridhar, 2016). Current urban challenges include, but are not limited to, non-communicable diseases (i.e. obesity and hypertension), infectious diseases (i.e. COVID-19),

accidents and injuries, mental health, disaster risks and climate change (Siri, 2016). Therefore, management of urban and development areas is essential to ensure healthy populations and sustainable environments.

According to the World Health Organization (WHO) European Healthy Cities Network, a healthy city is conscious and committed to "continually [create] and [improve] its physical and social environments and [expand] the community resources that enable people to mutually support each other in performing all the functions of life and developing to their maximum potential" (WHO, n.d.). Developing healthy cities is also directly related to the United Nations Sustainable Development Goals (UNSDGs) such as zero hunger, clean water, climate action and institutions with peace and justice. More specifically, healthy cities can contribute to the collective goal of achieving inclusive, safe, resilient, sustainable cities and human settlements (UNSDG Goal 11) (UN Development Programme, 2016).

Healthy cities depend on the health of individuals and communities. Different international agencies and institutions had devised various indicators to monitor the health of their cities such as measuring health outcomes (total mortality, lower birth weight), health services (immunization rates, health insurance, per capita healthcare services), the environment (air pollution, water quality, greenspace, public transport access, cycling routes) and socioeconomic indicators (unemployment, poverty, availability of childcare, and housing) (Webster & Sanderson, 2013). As humans live within built and natural environments, these contexts can have a significant influence on health. In general, urban policies and planning of cities are undeniable forces and critical determinants of health that influence people's built environments and living

conditions (Barton, 2009; Boarnet, 2006; O'Donnell, 2003; Renalds et al., 2010). For example, healthy urban planning can promote healthy and active lifestyles, enhance social cohesion, provide good quality housing, employment opportunities, education, and food, and also ensure safety and equity of social capital development and distribution of goods and services (Barton & Grant, 2013).

An analysis of surveys from 51 international cities showed that urban planning for healthy cities faced numerous challenges such as growth pressures, environmental quality improvement, infrastructure planning, housing, greenspace and physical activity promotion with one of the biggest challenge being transportation and access to good quality facilities such as education, culture, leisure, retail and healthcare (Barton & Grant, 2013). As further highlighted by the COVID-19 pandemic, the access to essential services such as healthcare and grocery store should continue to be considered an integral component of a healthy city during post-pandemic planning (Allam et al., 2022; Guzman et al., 2021).

In general, physical environments such as transportation, land use and neighbourhood walkability can shape behaviour patterns such as physical activity and social interaction, and mitigate environmental exposures such as air pollution, traffic and noise. The combination of individual behaviour changes and physical environment stressors has impacts on physiological changes such as increased stress and systemic inflammation, which may lead to chronic physical and mental health impacts (Brauer et al., 2013; Frank et al., 2019; Marshall et al., 2009). More specifically, many types of public facilities such as recreation, healthcare, employment, and food establishments can also influence the overall well-being of a community. Important recreation

facilities that improve health include green spaces, sports centres, libraries, and shopping centres (Doiron et al., 2020; Frank et al., 2006, 2019; Nathan et al., 2018; Northridge, 2003; Renalds et al., 2010). The following section defines equity in access to essential service, then summarizes the potential health and community benefits from access to six selected essential services which can contribute to healthy city planning.

1.2 Equity in Access to Essential Services

Access an accessibility can have multiple meanings in the contexts of transportation and urban planning. For example, TransLink BC supports accessibility in the entire transit system as a principle to accommodate people with different physical abilities by providing unobstructed sidewalks, curb ramps and audible signage at pedestrian crossings (TransLink BC, 2007). While this use of accessibility is important, another definition of accessibility, the focus of this thesis, is the "potential of opportunities for interactions" or the ease of reaching a destination that provides a service (Hansen, 1959). Accessibility can be also defined as "people's overall ability to reach desired services and activities", which is modified by mobility (ease of movement), geographic proximity, transportation connectivity, affordability, and social acceptability (Litman, 2021). Such accessibility is not always equitable across society; therefore, this thesis defines this issue as equitable access to essential services.

Inequality and inequity are often used interchangeably, but they are two distinct concepts. Equality simply refers to having equal opportunity while the equality outcome is not guaranteed. Inequity refers to "unfair and avoidable differences arising from poor governance, corruption or cultural exclusion" and is related to fairness and justice (Global Health Europe, 2009). Fairness and justice can also be called social equity, which determines the appropriateness of distribution

of benefits and costs of various services (Litman, 2022). More specifically, health equity refers to the "absence of unfair and avoidable or remediable differences in health" among population groups due to social, economic, demographic, or geographic differences (WHO and Pan American Health Organization, n.d.). Equity is largely influenced by institutional policy and planning. Since various essential services related to urban planning that can affect health and access to these services across the population needs to be considered in evaluating a healthy city. More specially, equitable access to essential services falls under the broader concept of transportation equity.

Five categories of transportation equity have been suggested and include 1) fair share of resources, 2) differences in external costs such as congestion delays, traffic risks and pollution one person imposes on others, 3) inclusivity of mobility need and ability, 4) affordability and 5) social justice (Litman, 2022). Each category of transportation equity is tied to transportation planning decisions that can influence transportation quality, development of service location and types and therefore access to different land use and economic activity (Litman, 2022). Having the "fair share of resources" is the first step in addressing transportation equity and complements the other aspects, which refers to "people with similar needs and abilities should receive a similar share of resources and bear similar shares of cost" (Litman, 2022). Therefore, the fair share of resources and services in transportation equity is called equitable access or accessibility to essential services.

1.3 Benefits of Accessing Essential Services

Healthcare Facilities

Quality of healthcare and health outcomes can be linked to three important factors: availability, acceptability, and access of healthcare. In terms of physical access, various factors influence people's healthcare-seeking behaviours such as travel distance, personal mobility, availability of alternatives, perceived distance modified by the urgency of the healthcare situation and flexibility of the facility. These physical and social barriers to transportation may lead to the abandonment of care-seeking, deterioration of health, and higher chances of visiting emergency rooms due to delayed care (Haggerty et al., 2014). A multi-region study in Canada showed that people's perceived access to healthcare may be related to self-reported mental health even more so than physical health status (Harrington et al., 2014). Poor health outcome due to lack of access was also seen in pediatric populations in Ontario where higher physician supply was associated with increased use of primary care visit, decreased utilization of emergency department and fewer hospitalization of acute infectious conditions (Guttmann et al., 2010).

Globally, the benefits of having access to primary care were also well documented such that having primary care can lead to better health outcomes such as increased life expectancy, better quality of life, satisfaction with care, adherence to treatment plans, management of chronic illness and fewer preventable disease, and low birth weight children (American College of Physicians, 2008; Aminto, 2012; Mold, 2014). Healthcare quality was also influenced by the availability and acceptability of care in addition to the access of care. Factors impacting healthcare availability and acceptability include wait time, language barriers, physicians' attitudes and information about follow-up care and many other factors (Sibley & Glazier, 2009). However, a patient's ability to have access to healthcare is the first step to improving health.

Grocery Stores

Areas with poor access to healthy food and grocery outlets can be defined as "food deserts" (Beaulac et al., 2009; Cummins & Macintyre, 2002). While the location of grocery stores varies based on various factors, the impact of "food deserts" and food insecurity on individual and community health is unequivocal. Many studies in different countries show that greater access and availability to healthy food was associated with better dietary outcomes and quality such as more fruits and vegetables and less fast food intake (Black et al., 2014b; Larson et al., 2009; Moore et al., 2008). Lack of access to healthy food was also associated with the risk of obesity for people of all ages (adults, adolescents, and children) and gender. While the association between access to food and obesity was not always consistent in the literature due to inconsistency in methods and definitions of healthy food, better access to supermarkets was related to a reduced risk of obesity (Larson et al., 2009). Conversely, increased exposure to fast food and areas with higher access to fast-food restaurants wase associated with higher body mass index and obesity prevalence (Fleischhacker et al., 2011; Fraser et al., 2010). When healthy food was burdensome to obtain due to geographical factors and affordability issues, people were more likely to consume more fast food, which included higher fat intake. More fast-food consumption was also positively linked to children with higher BMI and negatively associated with eating fruits and vegetables (Fleischhacker et al., 2011; Larson et al., 2009). Other factors associated with access to healthy food include the promotion of healthy dietary behaviours, physical activity and decreased sedentary behaviours (Li et al., 2019). Access to healthy food and grocery stores was not purely a geographic issue but a social issue that depends on economic factors, transportation and time use (Widener, 2018). For instance, food access may be more difficult for individuals who do not have a typical work schedule and rely on grocery stores to open for

longer hours at night time or early morning (Widener et al., 2017). Furthermore, increased access does not always correlate with increased consumption of healthy food due to personal perception and food affordability issues (Walker et al., 2010).

Greenspace

Numerous studies have shown that nature connection can positively impact life satisfaction and subjective well-being across different ages and occupations (Houlden et al., 2018; A. Howell et al., 2013; Nisbet et al., 2011). In terms of physical health, Cusack et al. (2018) found increased birthweight with increased exposure to greenspace in Vancouver and Toronto. Howell et al. (2011) also found that loss of tree canopy was associated with increased mortality related to cardiovascular and lower respiratory trace illness. There are many possible mechanisms explaining these health benefits such as greenspace's ability to buffer environmental exposure to air and noise pollution, reduced inflammation and oxidative stress, increased physical activity, and positive psychological conditions (Bosch et al., 2018; Cusack et al., 2018). Improved psychological conditions can be attributed to greenspace as a mediator for well-being. However, increased exposure to greenspace also has negative impacts to consider such as potentially increased exposure to aeroallergens, pesticides or herbicides, and zoonotic disease vectors (WHO, 2016).

Community Centres

Community centres are often multi-purpose spaces that have the flexibility to provide a wide range of services, activities, and programs that accommodate people of all ages, interests and ability levels, which help adopt a sense of community, increase people's social interactions,

community participation and trust in the neighbourhoods (Helliwell & Putnam, 2004). In Canada, community belongingness had the most influence on improved exercise, weight loss, and lowered alcohol consumption. Increasing in healthy behaviour and lifestyle choices can be significantly attributed to exposure to health-related behaviours norms in the community and access to community resources, which can be delivered by community centres (Hystad & Carpiano, 2012).

Community belongingness also had stronger associations with mental health compared to physical health. For example, participation in art and cultural activities were associated with lower self-reported anxiety, depression and the need to consult a general practitioner for mental health and emotional problems (Renton et al., 2012). Social capital is an essential element of social well-being that help provide communities with acceptance, safety, and support for their members. Since community centres allow people of all ages and interests in a neighbourhood to gather, this leads to increased interaction with people in the community thus generating more trust and acceptance of others leading to more happiness and life satisfaction (Helliwell & Putnam, 2004; McMillan, 1996). Other studies have found that community social capital mediated the impact of flooding on social functioning in Australia, which showed the importance of community support in the context of disaster response (Zahnow et al., 2019). Therefore, community belongingness promoted by community centres had implications for Canada's pandemic response where an increased sense of belonging may strengthen the trust within a community, thus buffering the negative impacts of the pandemic and speeding up the recovery process.

Education Centres

Opportunity for education for all ages is important for the social fabric, economic development and individual well-being of society. Early childhood education such as childcare services was an important socialization institution for young children to interact with others to learn socialized behaviours and emotional understanding of others (Bakken et al., 2017). Access to childcare also has implications for parents since women often experienced gender expectations and sociocultural norms of taking care of children (Prentice & White, 2019). Without adequate and formal childcare, it limits women's options to participate in the workforce, which may lead to further economic stress for low-income families and reinforce social inequalities regarding women obtaining employment (Langford et al., 2019). This observation is consistent with other studies where access to childcare is associated with a higher probability of obtaining preferred employment among women with young children (Kawabata, 2014). Greater distance to childcare also reduced the family's likelihood of receiving childcare subsidies, which also has economic and health implications for the well-being of the child and family (Herbst & Tekin, 2012). Access to primary, secondary, and post-secondary schools is also important. Formal education during critical developmental periods has shown correlations to reading comprehension and critical thinking skills that can predict performance in secondary education and future career (Boland, 1993). Decreased geographic proximity to post-secondary education has been linked to a lack of university enrollment further exacerbated by financial costs and social barriers (White & Lee, 2020). Overall, quality education has been outlined as one of United Nation's Sustainability Development Goals where education enables upward social mobility and helps reduce inequalities by providing opportunities to escape intergenerational poverty (Abdin, 2018). As seen through school closures during the COVID pandemic, schools provide formal learning

while encouraging structured opportunities for physical activity, healthy food access and psychosocial support (Dove et al., 2020). Various programs within schools also have a significant influence on students' mental health, social engagement, and overall well-being.

Public Transportation

Access to public transit has significant implications for people's physical health, mental health, and social and economic well-being (Lee & Sener, 2016). As part of active transportation, increased public transit usage had been linked to increased physical activity, which had public health benefits such as reduced prevalence of hypertension, diabetes, obesity and osteoporosis (Frank et al., 2006; Lachapelle & Frank, 2009; Saelens et al., 2014). Further, people's perceived access to public transportation can impact life satisfaction, which can impact the frequency and continuation of transit usage to other essential services such as employment, education and grocery stores (Black et al., 2011; Foth et al., 2013; Lee & Sener, 2016; Tiznado-Aitken et al., 2020; Walker et al., 2010; Widener et al., 2017). The psychological burden of travel through lack of access also has an impact on people's social well-being. Decreased transit mobility can reduce people's social activity thus leading to the feeling of social exclusion and other mental health effects such as depression (Frank et al., 2006; Lättman et al., 2016; Lee & Sener, 2016; Saif et al., 2019). Reduced access to transit may also increase the cost and time of travel thus leading to limited access to employment, goods, and services, and affordable housing (Chow, 2020; Yang et al., 2020).

The existence of essential services described above will not have much influence on health and well-being if people cannot reach these places. The decision to utilize these resources also

depends on the attractiveness of the facilities and the attractiveness of the trip itself (via transportation). The consideration of access to services also includes the destination's physical proximity, connectivity, and perceived access. Therefore, land use and transportation are interconnected in the sense that "land-use patterns can influence the need for transport infrastructure and service; and transportation investments can change the land value and impact how land is developed" (Frank et al., 2019). Given the individual and community benefits of various essential services, one can argue that everyone in the same neighbourhood should have equal access to the same services; however, the reality may be different. The following section summarizes transportation equity and research that has evaluated equitable in access to essential services.

1.4 Current Evidence on Equitable Access to Essential Services

Many studies have evaluated access equity to services in international and Canadian cities based on demographic and socioeconomic characteristics and key findings are summarized in this section for the six essential services covered in this thesis. One preliminary analysis of land use and childhood development Metro Vancouver found less socioeconomically disadvantage areas have more vegetation while more socioeconomically disadvantage had higher proportions of built and paved spaces (Bosch et al., 2018) while another study of Vancouver, Burnaby and New Westminster found higher income census tracts had lower proportional access to greenspace in all three municipalities (Luo et al., 2020). Other studies in Germany and China have also found that neighbourhoods with populations of disadvantaged socioeconomic position such as low income, high unemployment, and low proportion of housing are associated with decreased greenspace availability (Schüle et al., 2017; Xu et al., 2017). In the US, poor access to greenspace is also associated with more socioeconomic disadvantaged populations as well as

increased concentrations of African Americans (Dai, 2011). An analysis of greenspace distribution in ten US cities also found a strong positive correlation between higher education and income with higher urban vegetation, indicating that access to greenspace is still a marker of privilege in the US (Nesbitt et al., 2019).

An analysis of the availability of the bus system in Metro Vancouver revealed that New Westminster and Vancouver had the highest ridership, while municipalities with poor accessibility include Tsawwassen, Langley, Maple Ridge and Pitt Meadows (Chow, 2020). Two studies in Toronto found that the lower income neighbourhoods or more socially disadvantaged areas had better transit accessibility and lower transit times (Allen & Farber, 2019; Foth et al., 2013). Access to public transit had also been well studied in other international cities. A study of people's walking accessibility to transit facilities in Madrid showed that younger adults, men and immigrants were more willing to walk longer distances to transit and were less sensitive to increased walking distance to transit compared to older people, women, and non-immigrants (García-Palomares & Gutiérrez, 2012). Another analysis of transit accessibility in Chicago showed that areas with low accessibility had "higher percentage of African-Americans, Hispanic, Asians, low-income workers, low-educated citizens and the elderly", which showed inequity in access to public transit (Ermagun & Tilahun, 2020).

In terms of access to education in the US, socially advantaged students typically had greater access to favourable school environments, better courses and teachers where access to different quality of education was significantly determined by social and ethnic inequalities (Raudenbush et al., 1998). While Canada has free and compulsory education up to the high-school level,

inequity of access to education still exists for certain marginalized groups such as Indigenous peoples, visible minorities and lower socioeconomic status individuals (Potvin, 2017). Factors that influence access to food may depend on food store density, cost, perception of food access, socioeconomic status, and ethnicity. In the US, areas with lower income had 30% fewer supermarkets than neighbourhoods with higher income and fast-food chains were more prevalent in areas with a higher concentration of ethnic minority groups (Fleischhacker et al., 2011a; Walker et al., 2010). These results were slightly different from food access equity studies in Canada. One study in Hamilton, Ontario showed that there were half as many grocery stores and three times as many convenience stores in the low-income area (Latham et al., 2007). In Montreal, the distance to the grocery stores was the shortest for middle-income areas compared to other income levels (Apparicio et al., 2004). Similarly, two studies in Edmonton showed socioeconomic deprivation was linked to high prevalence and access to fast food restaurants (Smoyer-Tomic et al., 2006; Hemphill et al., 2008). Access to food was less studied in BC; however, it was reported that 11.8% of households and roughly half-million people in BC had experienced some level of food insecurity (Vancouver Coastal Health, 2016).

In addition, access inequity to healthcare had always been a major focus even with universal healthcare in Canada. A Statistics Canada study (2016) reported that 29% of Canadians who needed healthcare reported having difficulty accessing these services in 2013 (Government of Canada, 2016). Other Canadian studies had also reflected that seniors and suburban residents had fewer opportunities to access healthcare compared to the rest of the population where access and service density were both low (Paez et al., 2010). A study in Ontario also underscored the need to assess the current distribution of healthcare providers in Canada by demonstrating that

counties with the highest supply of physicians had the highest median household income and areas with a greater supply of physicians had greater self-reported access to care, fewer hospitalization for common acute infectious conditions, and fewer acute worsening for children with asthma and diabetes (Guttmann et al., 2010). A multi-province study reported that BC had the highest unmet healthcare needs compared to all other provinces (Sibley & Glazier, 2009). A projection study of Surrey, BC (a municipality of Metro Vancouver) further showed that over 27,000 more people (50% of them being seniors) will not have access to a hospital in under thirty minutes by 2022 due to rapid population growth and healthcare catchment expansion in the future (Mayaud et al., 2019). Access inequity in healthcare may be due to the observation that areas with higher education levels tend to attract more physicians; thus leading to physicians concentrated in high-status areas (Krishnan, 1997).

In addition to geographic barriers to accessing healthcare, barriers related to the systemic and institutional organization of healthcare also exist for various marginalized groups who are often excluded from mainstream social, economic and cultural activities (Sevelius et al., 2020). For example, immigrants in Canada face tremendous barriers when accessing healthcare due to communication barriers such as cultural and language differences. There may also be socioeconomic and knowledge barriers such as not knowing where to obtain resources and how the healthcare structure differs from their home countries (Ahmed et al., 2016). Women and older immigrants also face intersectional challenges when seeking healthcare in Canada. While it is not unusual for most Canadians to experience long wait times in emergency department visits, women might suffer more from economic losses due to absence from work or not having enough family and child support when accessing healthcare (Turin et al., 2020). Elderly immigrants

might also experience more barriers due to differences in health literacy, cultural and health beliefs compared to younger immigrants (Guruge & Montana, 2019). Therefore, access inequity is still a major issue in Canada where lack of access may lead to worse health outcomes.

The above social and cultural challenges outlined were also not unique to healthcare as various marginalized populations, such as Indigenous communities, in Canada experience access inequity to all types of essential services (Nelson & Wilson, 2018; Nguyen et al., 2020). While the previous section discussed the health benefits of having access to essential services for individuals and the community, this section highlighted current findings on access inequity and thus transportation inequity, which was different for different regions and services. For example, fewer research efforts have focused on access to education, public transportation and community centre compared to greenspace, healthcare and grocery stores. Furthermore, a comprehensive analysis of access inequity to various services was also lacking for the Metro Vancouver region, which was a research gap that needed to be addressed.

With the understanding of benefits and current inequity studies of access to essential services, the next section discussed approaches to urban planning and methods of making services more equally accessible to people and communities.

1.5 Mobility vs. Proximity: Envisioning Walkable Neighbourhoods

Two distinct urban planning concepts are relevant to this thesis and the "15-Minute City" framework: mobility-based and proximity-based planning.

Mobility-based transportation planning refers to using road expansion and improvement to accommodate vehicles as solutions to improve traffic congestion and increasing transportation

(Litman, 2021). While this approach has consistently been used in past and current planning, it also highlights numerous problems with traditional urban planning approaches that focus on mobility rather than proximity (Handy, 2020). Mobility-based approaches are mostly concerned with improving the physical infrastructures of transportation such as roads and even bike lanes. This approach maximizes travel speeds of cars or bikes through having more lanes, which may temporarily solve the issue of traffic congestion and increase travel speed. However, more automobile convenience may also encourage more drivers to drive on the road which can cause more congestion once again, thereby not completely solving the initial problem of travel impendence (Handy, 2020; Litman, 2013). Therefore, mobility-based transportation planning may end up in a vicious cycle.

Mobility-based transportation planning also influences health through multiple pathways such as decreased traffic safety, increased air pollution and noise. In 2020, there were 1745 cases of fatal motor vehicle accidents and over 100,000 total injuries due to vehicle collisions in Canada (Government of Canada, 2022c). In terms of air pollution, an estimated ten million or 32% of the Canadian population was exposed to traffic-related air pollution near major urban roads or highways (Brauer et al., 2013). The combined exposure to traffic injuries, air pollution and noise had been linked to higher BMI, systematic inflammation and stress which all have significant physical and mental health effects (Frank et al., 2019). Shifting away from mobility-based urban planning can reduce people's dependency on fossil fuel consumption, time and stress burden from daily commutes and increase life satisfaction and prosocial behaviours (Lee & Sener, 2016; Newman & Kenworthy, Jeffrey, 2015).

More importantly, mobility-oriented planning also specifically benefits people with car ownership; thus excluding people who do not have access to or cannot afford automobile travel which does not represent an equitable and sustainable approach to urban planning. Mobility-based transportation planning directly contradicts transportation and access equity since private car ownership relates to the issue of affordability and the external costs are not equitable distributed across society (Litman, 2022).

In contrast, proximity-based planning involves increasing access to services, which brings services closer to people instead of increasing the speed of reaching these places by use of vehicles. By having services closed to people, they have more destination choices within walking or cycling distance. In Metro Vancouver, adults who live in the top 25% of most walkable areas drive 58% less than those in less walkable areas. Quantitatively, residents in highly walkable neighbourhoods may experience fifteen to thirty minutes more walking per week compared to those in low walkable neighbourhoods (Sallis et al., 2004). Residents in the most walkable areas were also half as likely to be overweight and associated with increased physical activity (Frank et al., 2010; Renalds et al., 2010). However, it is also important to acknowledge that high walkability is sometimes associated with high levels of traffic-related air pollution (NOx), especially in low-income neighbourhoods (Marshall et al., 2009). In terms of other health benefits, more walkable neighbourhoods were associated with decreased prevalence of obesity, diabetes, depression, alcohol abuse and higher social capital (Creatore et al., 2016; Renalds et al., 2010). Proximity-based planning promotes active transportation, transportation diversity and equity through walking, cycling and public transit instead of relying on automobiles alone

(Litman, 2013). More services in a compact area, thus leading to more walkability, has a significant impact on a community's economic, social, and overall well-being.

1.6 Accessibility Measures

Having access to essential services means having ways of reaching different destinations and having choices between destinations, which is a critical component of good quality of life. Given that a minimum level of access to essential services satisfies people's basic living needs, equitable access to services becomes a measure of equitable distribution of opportunity (Pereira et al., 2017). Therefore, accessibility measures can act as a gauge for urban planning performance on the overall health and well-being of a community (Handy, 2020; Pirie, 1981).

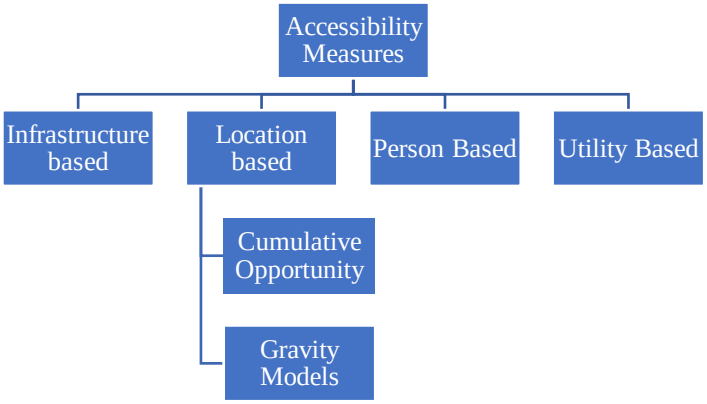

Figure 1 Different types of commonly used measures of access to services. Adapted from Geur & van Wee (2004)

Based on the benefits and current levels of inequity regarding access to essential services, there are also numerous measures of accessibility. As summarized by Geurs & van Wee (2004) (Figure 1), there are four basic accessibility perspectives which are infrastructure, location, person, and utility-based. Infrastructure-based measures analyze performances of transportation infrastructure such as congestion level and travel speed. This type of measure is most similar to the mobility-based approach in transportation planning mentioned above. Typically,

infrastructure-based measures were used in assessing time saved or speed increase of specific transportation network interventions (ie. high-speed rails) (Baş & Yüzer, 2020; J. Cao et al., 2013; Petzäll et al., 2011). A major disadvantage of such measures is that they do not account for the impact of land use at both the origin and destination and only assess the efficiency of the transportation method in most cases (Geurs & van Wee, 2004).

Location-based measures consider the travel time between locations and the spatial distribution of opportunity. One example of such a measure is cumulative opportunity, which measures the number of opportunities within a specific time and distance buffer from the origin of interest (Pirie, 1981). Early use of this method can be seen in Wachs & Kumagai (1973) who measured access to employment in Los Angeles. One of the disadvantages of using cumulative opportunity is that the probability of reaching two opportunities is deemed to be the same as long as they are within the same buffer distance or travel time. For example, two grocery stores (one five and one ten minutes away from a certain origin) are considered to have the same probability of being reached since they are both within ten minutes of travel. However, this does not reflect reality because distance or travel time should have an impact on access. To address such issues, gravity-based accessibility measures may be used.

In a gravity-based model, travel time and distance are accounted for within the access indicator such that an increase in distance or travel time equals a decrease in access (Geurs & van Wee, 2004; Hansen, 1959). Compared to cumulative opportunity, this measure may be more accurate because it accounts for the impact of distance and travel time on access. However, the operationalization of such method is not always straightforward because the opportunity-decay

function has to be devised and tailored to each study area (Pirie, 1981). Since the result often represents a probability measure, it is also not as easily interpretable as cumulative measures that use discrete counts of opportunities (Geurs & van Wee, 2004). Nonetheless, both location-based methods have their drawbacks such as not taking into account the personal characteristics of individuals who are travelling. Such drawbacks may be addressed using person-based measures.

Person-based measures also consider travel time between locations and spatial distribution of opportunities. In addition to those factors, it accounts for timing constraints such as business hours, activity duration and individual choices within the opportunity (Hägerstrand, 1970). For instance, a Beijing study on people's access to shopping activities used GPS devices to track participants' travel duration and frequency of daily activities such as work, leisure and running errands to model access to shopping activities. The person-based rationale was to identify and include individual spatial-temporal constraints in addition to geographical travel distances to more accurately model the access of a community (Ding et al., 2016).

The final commonly-used accessibility measures are the utility-based measures, which analyze the economic cost and benefit that people obtain through access to certain spatial locations, in addition to analysis of the spatial distribution of opportunities (Geurs & van Wee, 2004). These measures can be mixed with other methods such as infrastructure-based measures. For example, road investment programs in Sweden had been evaluated on their economic benefit, time gained, reduction of cost in accidents and vehicle costs (Forslund & Johansson, 1995). Other examples of utility-based measures may examine efficiency in public transport facility implementation such as cost saved, travel time and quality of service (Gulhan et al., 2013).

1.7 15-Minute City

The “15-Minute City” was coined by French-Colombian scientist, Carlos Moreno, in 2016 that directly applied the idea of a compact city with diverse land use in proximity to its residents (Kucharek, 2021). “15-Minute Cites” underscored the necessity for “proximity-based” services with safety, sustainability and resilience in mind where everyone should have access to living, working, commerce, healthcare, education and entertainment within fifteen minutes of travel (Moreno et al., 2021). The concept of “15-Minute City” is multi-layered but can be summarized by four converging ideas and pillars. The four ideas focus on promoting 1) social inclusion and cohesion, 2) adaptive urban infrastructure, 3) digital revolution and 4) the considerations of climate change and other environmental problems. The four pillars focus on density, proximity, diversity and digitalization within future urban development (Allam et al., 2022; Moreno et al., 2021). Density considers the optimal number of people in each area where resources can be adequately distributed and utilized. Proximity considers both spatial and temporal locations of essential facilities (i.e., work, health care, education) to reduce time spent in traffic. Diversity advocates for mixed land use in each area with diverse services choices to meet individuals’ needs. With the current trend in technology and innovation, it is impossible to avoid the digitization of services, which can enhance the experience of the previous three pillars of urban development. Digitization allows real-time delivery of services to people instead of people having to access these services such as food delivery or virtual communication between people online. Digital platforms also allow more equitable distribution of opportunity at reduced economic costs such as bike-sharing applications, which reduced the need to own a bike or car (Allam et al., 2022; Moreno et al., 2021).

The “15-Minute City” focuses on access and proximity rather than mobility to adopt “long-term planning [that] would result in a higher quality of life as proximity to basic services would help in saving time wasted in traffic, thus promoting sustainable mobility” (Moreno et al., 2021). With the advocacy for high density and mixed land use communities, the "15-Minute City" also promotes social inclusion as a result of the development of more public parks and public services accessible by walking and biking (Moreno et al., 2021). This concept had been embraced by many cities and international organizations such as the C40 Cities, World Health Organizations, UN Habitat and the Organization for Economic Co-operation and Development as it aligned with the UN Sustainable Development Goal 11 Sustainable Cities and Communities (C40 Knowledge Hub, 2020; Organisation for Economic Co-operation and Development OECD, 2020; UN Habitat, 2020; United Nation, 2015).

Currently, Paris, Barcelona, Portland, Shanghai, Singapore and Melbourne had also adopted urban planning strategies that include the concept of 15- or 20- minute cities (Wiewel & Kafoury, 2012; Land Transport Authority, n.d.; Pisano, 2020; Pozoukidou & Chatziyiannaki, 2021; Wu et al., 2021). While Metro Vancouver’s urban planning strategies had not explicitly adopted the “15-Minute City”, the *Metro Vancouver 2040* regional growth strategy plan highlighted the goals to improve the proximity of economic opportunities to where people live, develop healthy and complete communities with access to diverse services and amenities, and encourage active transportation such as transit, multiple-occupancy vehicles, cycling and walking, which all directly align with the concept of “15-Minute Cites” (Metro Vancouver, 2020). Correspondingly, Metro Vancouver’s municipalities also identified the need to develop more walkable and close-knitted communities with more services for sustainable development in

their respective *Official Community Plans* (Table 3), which is suitable for a "15-Minute City" analysis.

1.8 Rationale

This project was conducted as part of the "Pathways to Equitable Healthy Cities" global partnership that aimed to improve population health, health equity, and sustainability in urban cities. One of the key determinants of a healthy city was having access to essential goods and services such as education, healthcare, food, community centres, public transit and parks. These community features had been summarized as key constituents of a healthy and equitable neighbourhood considering their ability to promote more social participation and healthy behaviours (Macintyre et al., 2002; Northridge, 2003; Northridge & Freeman, 2011; Vannier et al., 2020). Since access to and essential services themselves were determinants of a healthy community, current levels of access to essential services in Metro Vancouver need to be evaluated. Even in international cities, analysis of access to services is often focused on one type of service at a time, which does not realistically reflect the holistic needs of individuals and communities (Aminto, 2012; Sharkey, 2009; Smoyer-Tomic et al., 2006).

This study was designed to improve the current understanding of access equity to multiple essential services in Metro Vancouver, encompassing concepts of access equity, complete and diverse communities, and sustainable development. The broad goal of this study was to identify areas with potential inequitable distribution of services within Metro Vancouver from the perspective of the "15-minute City. This study uses a cumulative opportunity measure to evaluate equity of access to essential services in Metro Vancouver under the "15-Minute City" framework. This work aligns with Metro Vancouver's regional planning goal of achieving

compact cities, complete community and sustainable development. This goal promotes social inclusion, equity, and service proximity, which can help realize the future of sustainable development with better community health and more living choices.

Geography is not the only barrier to services such that health outcomes and services received by individuals may still vary based on other socioeconomic issues and the lack of appropriateness of services (Beaulac et al., 2009; Kim & Wang, 2019; Winkleby et al., 1992). Nonetheless, understanding the geographic differences and distribution in access is the first step in addressing inequity. After geographic barriers of access are understood and adequately addressed, improvements to the services themselves can be accomplished to better serve the community.

1.9 Objectives

The main research objective of this project was to assess and describe the current level of access to essential services for neighbourhoods across Metro Vancouver. More specifically, this project analyzed the access to community centres, grocery stores, healthcare facilities, education facilities, public transit, and greenspace within fifteen minutes of walking. Equity in access was also evaluated by municipality, population density, age, and situational deprivation as a proxy for socioeconomic status. A detailed rationale for selecting the essential services and accessibility measures is described in section 2.3.1.

The broader aim of this study was to help regional and municipal planners and policymakers identify areas within Metro Vancouver with poor access to essential services to target resources to reduce gaps in access inequity. Through the investigation of population density, age and situational deprivation as a proxy for socioeconomic status, this study may also identify

populations experiencing intersectional effects of service deprivation. With the information from this study, service and amenity planning and urban planning, in general, can build a stronger lens for healthy cities. Furthermore, future comparative analysis between cities in the "Pathways to Equitable Healthy Cities" project can be done to evaluate access inequity between global cities.

Chapter 2: Methods

2.1 Study Context

This thesis was focused on Metro Vancouver, the third most populous urban centre in Canada. Metro Vancouver is composed of 21 municipalities, one Electoral Area and one Treaty First Nation across 2,883 km² of land area. These municipalities include Village of Anmore, Village of Belcarra, Bowen Island Municipality, City of Burnaby, City of Coquitlam, City of Delta, Electoral Area A, City of Langley, Township of Langley, Village of Lions Bay, City of Maple Ridge, City of New Westminster, City of North Vancouver, District of North Vancouver, City of Pitt Meadows, City of Port Coquitlam, City of Port Moody, City of Richmond, City of Surrey, Tsawwassen First Nation, City of Vancouver, District of West Vancouver and City of White Rock. As of the most recent 2021 Census Data, Metro Vancouver had 2,642,825 people, which was projected to increase to 3.6 million by 2050 (Government of Canada, 2022b; Metro Vancouver, 2018).

2.2 Origins

The origin data include dissemination areas (DAs) within the Metro Vancouver boundary while destinations may be outside of the Metro Vancouver boundary. This considered peripheral neighbourhoods of Metro Vancouver that could travel both in and out of the regional boundary for their essential services. The population-weighted Dissemination Area (DA) centroids from the 2016 Statistics Canada Census were used as proxies for neighbourhoods in Metro Vancouver (n= 3444). The 2016 Census Data was the most recent data at the time of analysis. DAs were the smallest unit of geographic area with relatively stable boundaries over time and uniform population sizes of 400 to 700 people (Statistics Canada, 2018). The data source for the DA

centroids and Metro Vancouver boundary files were listed in Table 1. Data from Statistics Canada was filtered by the Census Division Name (CDname.DRnom) “Greater Vancouver” to obtain geographic coordinates of DAs in Metro Vancouver only. According to the Statistics Canada 2016 Census, eight DAs had zero population. The mean and maximum size of all the DAs in Metro Vancouver were 0.19 and 386.9462 KM^2.

Table 1 Metro Vancouver origin and municipal boundary data

Data Name	Year	Source
Population weighted Dissemination Area centroid	2016	Statistics Canada (2021)
Metro Vancouver municipality boundary	2020	Metro Vancouver Open Data Catalogue

2.3 Destinations

2.3.1 Selection of Destination for Cumulative Opportunities Measure

Since the objective of this study was to assess current levels of access to essential services in Metro Vancouver, essential services had to be selected as destinations. To rationalize the choice of essential services, the fundamental human rights can be first considered such as rights to food, education, healthcare, and an adequate standard of living (United Nations, 2015). To supplement the adequate standard of living, greenspace, community centres and public transit were also essential parts of socialization with various community benefits that resonate with Metro Vancouver’s regional goal of developing complete, diverse and sustainable cities (Renalds et al., 2010; Metro Vancouver, 2020). In summary, the final decision on the six essential services was informed by essential services defined in current international regional plans and studies that

adopted the "15-Minute City" concept and Metro Vancouver's regional and municipal goals and strategies. The inclusion of specific subcategories of the six essential services also depended on data availability.

2.3.1.1 Applications of the "15-Minute City Concept"

In the 2021 official introduction of the "15-Minute City" concept, Moreno et al. summarized six essential urban social functions to be included in a "15-Minute City" such as living, working, commerce, healthcare, education, and entertainment. Since the "15-Minute City" concept was first proposed, Paris was one of the first cities to adopt the concept at a policy level with the essential services considered being food, learning, work, shopping, outdoor, cultural engagement, healthcare, transportation, and sports (Arnarsdóttir, 2020). Since then, various official regional plans and studies had applied the "15-Minute City" concept in their respective regions each with different definitions of essential services. This implied that services within "15-Minute Cities" can be modified and tailored to each different international region.

In various international city official plans and studies, six essential services (greenspace, public transportation, education, healthcare, grocery stores, and community centres) consistently appeared in all the regions while other services vary from region to region such as employment, sports venues, and financial service (Table 2). This demonstrated that the six essential urban services mentioned in the original "15-Minute City" concept may be modified to meet the demand of different regions. Therefore, the destination choices of essential services for this study were unique to Metro Vancouver and the final choices were informed by Metro Vancouver's regional and municipality plans.

Table 2 An analysis of essential services included in international regional plans and studies that incorporated the "15-Minute City" Concept. [a](Wiewel & Kafoury, 2012); [b](Plan Melbourne, 2017); [c](Arnarsdóttir, 2020); [d](Land Transport Authority, n.d); [e](Wu et al., 2021); [f](Guzman et al., 2021); [g](Bright, 2021)

Regions	Greenspace, Public Transportation, Education, Healthcare, Grocery Stores, Community Centres	Other Services Included
Official Regional Plan		
The Portland 20-Minute Neighbourhoods[a]	√	Employment, community gardens, senior housing
The Melbourne 20-Minute Neighbourhoods[b]		Employment, playground, community gardens, playgrounds
Paris En Commun[c]		Sports, cultural engagement venues
Singapore: 20-Minute Towns and a 45-Minute City[d]		Business parks, industrial estates, retail shops
15-Minute City Studies		
Shanghai, China[e]	√	Convenience shops, entertainment venues, financial services

Bogota, Colombia[f]		Shopping, sports, home duties
Chicago, United States[g]		Libraries

2.3.1.2 Metro Vancouver Policies

During the initial stages of the COVID-19 pandemic in 2020, many areas in the world experienced travel restrictions in their daily lives including Metro Vancouver. As a response to the pandemic, the BC provincial recommendations officially listed recommended essential services that helped in the development of this study. Within the plan, essential services included healthcare, food services, transportation, community services, parks, and education. Other services mentioned in the plan include sanitation, community, and law enforcement; however, those services were not typically accessed by the general population (Government of British Columbia, 2020).

In addition to the pandemic response, we also investigated regional and municipal plans to determine essential services that are specifically important to Metro Vancouver. While Metro Vancouver has not officially adopted the "15-Minute City" concept, current goals and objectives set by these official plans followed similar concepts such as accessibility, inclusive and sustainable development consideration, which acted as additional support for the destination choices of this study. For example, the *Metro Vancouver 2040* plan outlined Goals 1, 4, and 5 as creating compact urban areas, developing complete communities and supporting sustainable transportation. As a specific example, the *Metro Vancouver 2040* Strategy 4.2 mentioned developing "healthy and complete communities with access to a range of services and

amenities", which included the need for greenspace, public transportation, education, healthcare, grocery stores, and community centres (Metro Vancouver, 2020). Similarly, official municipal community plans from major municipalities in Metro Vancouver also directed mentioned the need for six essential services included in this study (Table 3). A full description of the objectives, goals and strategies from each plan can be found in Appendix A.

Table 3 Regional policies that highlight the importance of access to goods and services

Regional Plan	Greenspace	Public Transit Stop	Education	Healthcare	Grocery Store	Community Centre
Metro Vancouver 2040	Strategy 4.2	Strategy 5.1-5.2	Strategy 4.2	Strategy 4.2	Strategy 4.2	Strategy 4.2
City of Burnaby Social Sustainability Strategy (2011)	Priority 3	Priority 5	Priority 1	Priority 1	Priority 1	Priority 3
City of North Vancouver Official Community Plan (2014)	Goal 5.2-5.3	Goal 2.1-2.3	Goal 5.2	Goal 3.1	Goal 3.1, 3.4	Goal 5.2-5.3

City of Richmond Official Community Plan (2012)	Objective 3.2.3	Objective 3.1.2, 3.2.5	Objective 3.2.4	Objective 3.2.4	Objective 3.1.2	Objective 3.1.2, 3.2.5
City of Surrey Official Community Plan (2013)	Theme B Objective 4	Theme B Objective 3	Theme F Objective 6	Theme F Objective 6	Theme F Objective 5	Theme F Objective 6
City of Vancouver Healthy City Strategy (2016)	Goal 8	Goal 11	Goals 1 and 9	Goal 4	Goal 3	Goal 4
District of West Vancouver Official Community Plan (2018)	Goal 2.8	Goal 2.4	Goal 2.9	Goal 2.3	Goal 2.9	Goal 2.8

Thus, based on international applications of the "15-Minute City" concept, specific regional goals of Metro Vancouver, and data availabilities the six essential services that were consistently mentioned and used for this study were greenspace, public transportation, education, healthcare, grocery stores, and community centres. Other services such as employment and sub-categories related to food such as food fast restaurants were not included in this study with rationale in section 2.3.5.

2.3.2 Data Source and Definition

Destination locations were assembled through a combination of data from British Columbia Open Data Catalogue, Open Street Map, DMTI Enhanced Points of Interest V2013.3, municipality website and TransLink BC (Table 4; see Appendix B for detailed links). All data were verified and processed into files with object ID, latitude and longitude. The detailed description and definition of each destination category are listed in subsequent sections.

Table 4 Destination name, year (last modified) and source

Destination Type	Year	Data Source
Greenspace	2020	British Columbia Open Data Catalogue
Public Transit Stops	2019	TransLink BC GTFS Data
Schools	2013-2021	DMTI Enhanced Points of Interest V2013.3 and British Columbia Open Data Catalogue
Daycare	2021	British Columbia Open Data Catalogue

Hospitals and Emergency Rooms	2020	British Columbia Open Data Catalogue
Urgent and Primary care centres	2021	
GP/walk-in clinics	2021	
Pharmacies	2021	
Mental Health and Substance Use Health Services	2021	
Grocery Stores	N/A	OpenStreetMap (OSM)
Community Centres	N/A	Municipality websites

2.3.3.1 Greenspace

Greenspace data was published by GeoBC in the BC Open Data Catalogue. Greenspace data include parks (all local, regional, provincial, and federal), greenspace, conservation areas, trails, athletics areas, playground, golf course, cemetery, plaza, water access and civic facilities (Table 5). Spatial boundaries of each greenspace were sourced from multiple municipal and regional district websites, Open Government Licence datasets, websites and PDF maps of publicized parks and greenspaces. All boundaries were also wedge-matched and verified to the ParcelMap BC cadastre (Government of British Columbia, 2017).

This data source was chosen over other measures such as the normalized difference vegetation index (NDVI) because the land use data from BC Open Data Catalogue only included

greenspace open to the public whereas NDVI might detect privately owned greenspaces such as private lawns or backyards, which are not accessible to the public.

Table 5 Greenspace data and definition (Government of BC, 2017)

Greenspace Type	Description
Regional	A larger park usually operated by the regional district
Local	Operated by the municipality or the regional district.
Private	Privately owned but open to the public (ie. golf course or conservation area)
Federal	Managed by the federal government but not classified as a national park like historic sites and federal lands such as ports with parks or green space components.
Provincial	Owned and managed by the provincial government but is not classified as a provincial park.
Park	Used for general or mixed purposes
Green Space	A primarily undeveloped space as a natural area.
Conservation Area	An area with ecological value such as nature parks, reserves, preserves, conservation, ecological management and wildlife areas.
Trail	Used for non-motorized travel (ie. walking, cycling, or equestrian paths or trails connected to green spaces)
Athletic	Outdoor sport and athletic activities spaces (ie. soccer, baseball, football fields, running tracks, tennis or basketball courts, bike parks and skate parks)
Playground	A small park with play equipment

Golf Course	A public or private golf course
Cemetery	A public or private cemetery
Plaza	An outdoor gathering space with benches, fountains, or monuments
Water Access	Provide waterfront and beach access right of ways and boat ramps
Civic Facility	Any civic facility associated with outdoor green space (ie. a museum, recreation centre or arena)

2.3.3.2 Transit Stops

TransLink public transit stop data was created from the General Transit Specification Feed, which was publicly available and required no further data processing. Transit stops include all locations where vehicles pick up or drop off passengers (Lesack, 2019). While each transit stop may have different service frequency and routes, this study accounts for all transit stops as a potential opportunity to reach different places.

2.3.3.3 Education

Childcare data was obtained by the BC Open data catalogue, which was published as a resource to maintain a list of ministry-funded licensed childcare locations and services. Education facilities beyond childcare were obtained through the DMTI Enhanced Points of Interest V2013.3, which included elementary, secondary, post-secondary and vocational training institutions (Table 8). For data completion, school enrolment data from the BC Open Data Catalogue was also used to locate schools with indigenous language and culture, early French immersion, and other types of education facilities. Data from these two sources were combined for the final data.

This study recognizes that not all education centres are suitable for everyone, and demand may vary by age. For example, families with young children need childcare and primary schools more than post-secondary education centres while older adults might benefit from having vocational schools rather than childcare service locations. Since this study looks at access for the public across Metro Vancouver of all ages, all levels of education are included. The assessment of individual level patterns of access is beyond the scope of this study.

2.3.3.4 Healthcare Centres

Healthcare centres include hospitals, emergency rooms, urgent and primary care centres, walk-in clinics, pharmacies, and mental health and substance use health services (Table 6). Different healthcare locations provide different needs and may not be suitable for all needs of all people. However, all healthcare services were considered together as potential choices for healthcare access in order to provide a broad measure of this service.

Table 6 Healthcare centre data and definition (Government of BC, 2022a-f)

Healthcare Centres	Description
Hospitals	Medical institutions with diagnostic and treatment services
Emergency Room	24-hours diagnostic and treatment services for people who have acute and life-threatening or severe illness
Urgent and Primary Care Centres	Same-day, urgent, non-emergency health care
Walk-in clinics	Specialized practices by groups of physicians operating within the provincial-territorial health system. They are available for patients

	that do not have family physicians or when their family physician is not available
Pharmacies	Prepare, preserve, compound and dispense drugs following prescriptions by licensed physicians
Mental Health and Substance Use health services	"Provide preventive, diagnostic and treatment services in a variety of community and hospital-based settings to help people achieve, maintain and enhance a state of emotional well-being, and the skills to cope with everyday demands without excessive stress or reliance on alcohol or other drugs" (Government of BC, 2022c)

2.3.3.5 Grocery Stores

Grocery stores include supermarkets, which carry a variety of products such as groceries, fruits, vegetables, and meats. This also included green grocers, which primarily sell fruits and vegetables (OpenStreetMap, 2021). Convenience stores (e.g., 7-11), corner stores, and smaller kiosks were excluded since the quality and variety of groceries cannot be ensured from store to store. Specific tags used for OSM were listed in Table 7.

Table 7 OpenStreetMap tags and definitions (OpenStreetMap Wiki, 2021; 2022a; 2022b)

OSM Tags	Description
Shop = grocery	Retail stores that specialize in selling fresh and non-perishable food such as a traditional grocery shop
Shop = supermarket	Full service and large groceries shops that sell meat and fresh produce
Shop = greengrocer	Shops that sell fruits and vegetables

2.3.3.6 Community Centre

These include all public indoor sporting and community complexes, recreation centres, pools, rinks, tennis centres and curling clubs from each municipal website in Metro Vancouver. Many indoor community complexes may also have outdoor activity areas. These are captured by the greenspace data listed above, which included civic facilities like outdoor community centre activity spaces. People may also gather and socialize in other places that are not officially defined as "community centres" such as libraries or churches. Given the broad range of services where people can gather may be difficult to define, this study limited community centres to publicly available indoor community activity centres. Community greenspace such as athletic fields that are located at community centers were captured as part of the greenspace measure.

2.3.4 Destination Data Processing

2.3.4.1 Greenspace

Using ArcGIS Version 10.8.1, the "Points Along a Polygon" function was used to delineate the outline of each greenspace polygon in intervals of fifty meters. To consider access to greenspace, the origin-destination pair mattered as soon as any point along the greenspace was reached. Therefore, outlining the greenspace made the travel time more accurate. The latitude and longitude of each point were calculated using the "Geometry Calculator" within the attribute table in ArcGIS.

2.3.4.2 Education

Education locations other than daycare centres were obtained using DMTI Enhanced Point of Interest V2013.3, which included elementary Schools, High Schools, colleges, Cégeps and

universities. DMTI queried keys contain Standard Industrial Code (SIC) and North American Industry Classification System (NAICS) codes (Table 8). Usually, one type of destination will have both SIC and NAISC codes. However, SIC covered a broader range of categories, which was queried first.

All destinations from SIC were combined and duplicates were removed by postal code. This process was repeated for each NAICS code. To further data completion, BC Open Data Catalogue was used to locate schools with indigenous language and culture, early French immersion and other types of education facilities. When SIC, NAICS and provincial data were combined, duplicates were removed once again by postal code.

Table 8 DMTI Enhanced Point of Interest Query Keys (DMTI Spatial Inc., 2013)

EPOI Type-EDU	Description
SIC 8211	Elementary school, secondary school
SIC 8221	College and universities
SIC 8222	Junior colleges and technical institutions
SIC 8243	Data processing school
SIC 8244	Business and secretarial schools
SIC 8249	Vocational schools
NAICS 61111	Elementary school, secondary school
NAICS 61131	College and universities and professional school
NAICS 61141	Business And Secretarial Schools
NAICS 61142	Computer Training
NAICS 61143	Professional And Management Development Training

NAICS 611511	Cosmetology And Barber Schools
NAICS 611512	Flight Training
NAICS 611519	Other Technical And Trade Schools
NAICS 61161	Fine Arts Schools
NAICS 61162	Sports And Recreation Instruction
NAICS 61163	Language Schools
NAICS 611692	Automobile Driving Schools
NAICS 611699	All Other Miscellaneous Schools And Instruction

2.3.4.3 Healthcare Centres

All healthcare data, except “Mental Health and Substance Use Health Services” had the same attributes where the “SL reference”, also known as the location key, provided a unique ID for each healthcare facility. ID, latitude, and longitude data were extracted for all data points and appended together where all healthcare locations were combined in the end. All duplicated healthcare facilities were removed based on postal code.

2.3.4.4 Grocery Stores

Grocery store locations were obtained from OpenStreetMap using the Overpass Turbo query application. The queried region was first confined to the Metro Vancouver Regional District, BC, Canada. Using the query builder, tags “shop= supermarket”, “amenity= grocery”, and “shop= greengrocer” were used to obtain 334, 335, and 68 data points, respectively. All locations were combined and duplicates were removed by comparing “id”, which was unique to every grocery store.

Grocery store locations were compared to data from DMTI Enhanced Point of Interest V2013.3. Queried keys for food stores in DMTI were listed in Appendix C. Although DMTI data contained more locations, it included convenient stores and corners stores (i.e., 7-11) as grocery stores and wholesale food retailers, which were not accessible to consumers directly. Since the goal of this study was to determine access to healthy and full-service grocery stores, the OSM data was preferred over the DMTI data.

2.3.4.5 Community Centres

Locations of community centres were open data on each municipalities' website. Latitude and longitude were located using Google Earth and OpenStreetMap. Other outdoor infrastructure can also provide community gatherings such as arenas and fields, which were already included in the greenspace data from British Columbia Open Data Catalogue and listed as "Civic Facilities".

2.3.5 Other Destinations Not Included

Other components included in the Moreno et al. (2021) definition of the "15-Minute City" include entertainment and employment. Entertainment was excluded because the range was too broad to characterize. For example, entertainment venues might include movie theatres, bowling alleys and bars. However, the level of health promotion and suitability for everyone is unclear.

While employment was an essential component of life and one of the main reasons for people to leave their house pre-pandemic, there was no known appropriate and high-quality data that includes all employment opportunities in Metro Vancouver. Past studies have used Statistics

Canada Census data as a proxy for employment. For example, they used the number of residents and commuters coming into the Census Tract as a proxy for the number of jobs in each tract (Deboosere & El-Geneidy, 2018); however, they were ultimately proxies and area-level data unlike other location data in this study, which were real geographic points. More problematically, access to employment also goes beyond a geographic issue since people have different qualifications and the same employment opportunity in one location has drastically different attractiveness according to different people. Since the pandemic, working from home has also become the new norm, which may predict ongoing changes to where and how people work in the future. Overall, the topic of employment is complex and therefore excluded from the current study.

Only full-service grocery stores were included as food outlets. Convenience stores were excluded, as they have more variability in the types of food they sell, and it was difficult to determine if they provided access to healthy foods. Similarly, restaurants and fast-food restaurants were excluded since the extent of “healthy food” choices was unknown. Moreover, not everyone considers dining out as essential considering the affordability and economic capacity differences between people.

Finally, locations that have a potentially negative association with health were excluded across all categories. For example, liquor stores (related to food) were excluded since the "15-Minute City" focuses on access to locations that promote a healthy and active lifestyle. Within-category quality or rankings of locations was not conducted.

2.4 Data Production

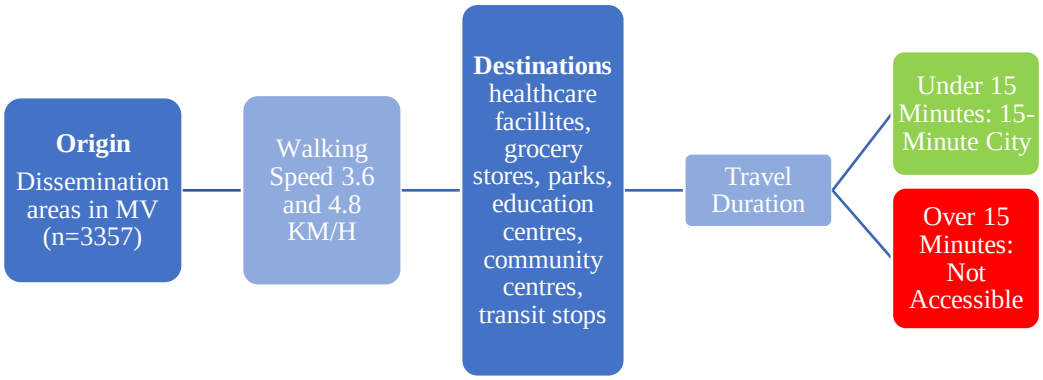

Figure 2 Data production overview

Access from the origins (DA centroids) to destinations (essential services) was calculated based on cumulative opportunity measure, specifically operationalized as the sum of the total number of opportunities available within fifteen minutes of walking from the origin by their respective walking speed (Figure 2). While not all essential services are equal (i.e., having a grocery store and food within fifteen minutes of walking might be more important than having a community centre because food is essential to life), all categories and subcategories of services are weighted equally for this study for simplicity and interpretability of results. This method was a straightforward measure of access under the "15-Minute City" concept. The results were also easily comparable between municipalities and other socioeconomic and demographic characteristics. Despite some limitations of this measure as described in the introduction, the cumulative opportunity was a suitable measure for this project because this method can provide basic, descriptive and easily understandable results of access that can be presented to Metro Vancouver's regional authorities and respective municipalities.

The walking time results were produced using the Rapid Realistic Routing with R5 package in R (R5R) with a detailed explanation in section 2.4.3 (Pereira et al., 2020). The road network for BC

was constructed using road network data from OSM, which was obtained via the Geofabrik Download Server. Travel matrices were constructed based on two different walking speeds. If the walking duration between a DA origin and all six destinations was within fifteen minutes, it would be considered a "15-Minute City" DA.

2.4.1 Walking Speed

Within the R5R package, travel time durations can be computed based on different travel speeds and modes. For this research, only walking was considered, and two walking speeds were 3.6 and 4.8 KM/H. The combination of mode, speed and origin-destination locations generated different travel durations for each DA in Metro Vancouver.

Factors that determine pedestrian walking speed include pedestrian density, gender, age, and seasonality (Knoblauch et al., 1996). Various field studies of people's walking speeds had shown a wide range of walking speeds among pedestrians of different ages (Bohannon & Williams Andrews, 2011; Knoblauch et al., 1996; Weber, 2016). Since walking speeds had shown a decline with age, significantly at age 65, this study simplified the different walking speeds based on age only. According to the US Highway Capacity Manual (2016), the average walking speed for younger pedestrians (under age 65) was 4.8 KM/H and 3.6 KM/H for older pedestrians (over age 65) (Transportation Research Board, 2016). The slower walking speed of 3.6 KM/H was also the default walking speed in the R5R routing algorithm.

While 3.6 KM/H represented the walking speed for people over the age of 65, it was a conservative estimate that represented people who walk slower for other reasons such as young

age (under age 14) or having limited abilities (Vaughan & Bain, 1999). The two speeds used likely underestimated people's real walking speed; however, this was reasonable since the broad research goal advocated for equity and inclusion.

2.4.2 Transportation Mode Exclusion

Cycling and driving modes were not included in this study since the "15-Minute City" concept underscored the importance of walkable neighbourhoods without having to rely on bikes or cars (Moreno et al., 2021). This advocacy for walking was also reflected in other international cities that incorporated the "15-Minute City" concept and Metro Vancouver's regional and municipal plans to achieve active transportation mainly through walking (Plan Melbourne, 2017; Wiewel & Kafoury, 2012; Metro Vancouver, 2020). Ideally, people should be able to walk to destinations that meet their daily demands while driving and cycling may perpetuate further access inequity within a city since possession of these transportation modes also depends on affordability and socioeconomic issues. Nonetheless, this study recognizes that active transportation, or human-powered transportation, is diverse and goes beyond walking and cycling to include modes such as longboards, kick-scooters and even canoeing, which can be analyzed in future studies (Government of British Columbia, 2019).

Motor vehicle travel or cycling analyses also require more analysis parameters such as level of traffic congestion, street topography and street design, which were features not available through the R5R routing algorithm. For the same reason, public transportation was not included in this study as a transportation mode due to consideration of walking to the transit stop, waiting for

time and congestion, which were beyond the scope of this research. Nonetheless, public transit as a destination was included.

2.4.3 Travel Time Calculation in R5R

The transportation road network was first set up in R5R using the route building function using the OSM road network data for BC. The geographic coordinates (latitude and longitude) of each origin and destination location were then imported separately into R. To calculate the travel time between each origin and destination pair, walking mode was set to “walking” with the two walking speeds (3.6 or 4.8 KM/H) and the maximum trip duration set to fifteen minutes based on the "15-Minute City" assumption. Overall, the R5R routing system took the shortest paths possible. The detailed procedure summary and R code can be found in Appendix D.

The R5R routing algorithm was verified. According to Geofabrik’s documentation of OSM, the road network contained “tags” such as residential roads, living streets, pedestrian streets, footway, paths, and steps, which can be recognized by the R5R routing algorithm when the transportation mode was set to “walking” (Ramm, 2021). This was tested between walking and cycling modes that yielded different travel times, which confirmed the R5R road network and the routing algorithm’s ability to identify different roads based on the transportation mode inputted. For example, when the walking mode was inputted, the R5R algorithm takes the shortest path according to the “tags” such as footway that cycling would not be able to access. The “tags” and R5R’s ability to recognize the utilize the tags justified the use of the OSM road network for this study since walking time computation was essential in this study.

2.4.4 Travel Duration Result Processing

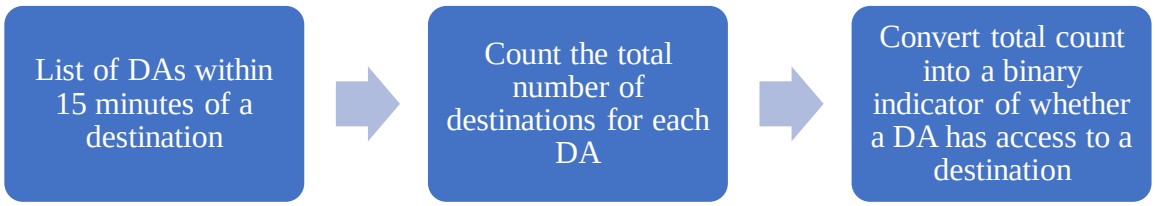

Figure 3 Travel duration output processing for each of the six essential service categories

After travel duration was computed for each origin-destination pair, travel duration was aggregated into counts of destinations within fifteen minutes for each DA. The travel duration output had a list of DA ID numbers with the destination ID they reached, and travel time in minutes. The number of destinations reached within fifteen minutes for each of the six essential service categories was aggregated for each DA individually. The total number of counts was then converted into a binary indicator (1- accessible within fifteen minutes; 0- not accessible within fifteen minutes) of whether a DA had access to an essential service type or not (Figure 3). The "15-Minute City" metric for each DA was then produced by the sum of the binary indicator with the highest being six (having access to all six essential services) to the lowest being zero (no access to any of the six services). Travel duration and total counts of accessible services may be used for future studies.

2.5 Variables

Equitable access to essential services can vary by geographic attributes of Metro Vancouver and other demographic and socioeconomic factors such as population density, age and socioeconomic status. Therefore, access equity in Metro Vancouver was also evaluated by these factors and the data sources were described in this section.

2.5.1 Municipal Boundaries, Population Size and Age

Municipal boundary, age structures, population size and area data for each DA were obtained from the 2016 Canadian Census Data (Government of Canada, 2016). The population density was calculated by dividing the population size by the area for each DA.

2.5.2 Socioeconomic Index

The situational deprivation dimension of the Canadian Index of Multiple Deprivation (CIMD) for the 2016 Census was used as a proxy for individual-level socioeconomic status (SES) in Metro Vancouver. Situational deprivation was determined by five Census data indicators: 1) proportion of the population that identified as Indigenous, 2) proportion of the population aged 25-64 without a high school diploma, 3) proportion of dwellings needing major repairs, 4) proportion of the population that is low income and 5) proportion of single-parent families. The index was created using the principal component factor analysis to create factor scores for each DA. Factor scores were ranked from lowest to highest with the lowest being the least deprived. Factor scores were then evenly divided by five to create the final quintile scale from one to five with one being the least deprived and five being the most deprived (Statistics Canada, 2019). Overall, three DAs had missing situational deprivation scores from the CIMD data. These missing values were spatially interpolated from values of neighbouring DAs.

This index was specifically used to represent socioeconomic status because it encompassed different factors that may influence SES such as income, education, and environmental conditions, which was more holistic than traditional SES indicators that only include household

income, occupation or education level. In the original documentation of the CIMD, the term "Aboriginal" was used. However, this study substituted "Aboriginal" with "Indigenous" as it is the preferred term used by Indigenous communities and peoples in Canada. The index's inclusion of the Indigenous population as a representation of situational deprivation may also reflect biases in generalizing Indigenous peoples as having lower socioeconomic status. An overall aim of this study is to help reduce inequity in access to essential services as one approach to mitigate effects of situational deprivation.

Three other dimensions in the CIMD, ethnocultural composition, economic dependency and residential instability, were not analyzed in this study. The CIMD index was a sub-national index for the BC province and not specifically developed for Metro Vancouver. This limitation significantly affected the usability of the ethnocultural composition dimension compared to the other dimensions. Since Metro Vancouver typically has a high population of visible minorities compared to other parts of BC, the ethnocultural composition index needed to be in higher spatial resolution to be specifically tailored to Metro Vancouver. The economic dependency measure partially considered age, which was already included in this study using the 2016 Statistics Canada Census data, while the residential stability measure partially considered apartment dwelling, which was also represented by population density.

2.6 Data Visualization

Result visualization and mapping were done using QGIS Version 3.20.0-Odense. Boundary shapefiles for DAs in Metro Vancouver were obtained from the Statistics Canada 2016 Census. Metro Vancouver DAs were filtered by CMA = Vancouver. All attributes described above were merged to the DAs shapefiles using the "Join Attribute by Field Value" function in QGIS.

Chapter 3: Results

3.1 Overview

Overall, 3357 DAs in Metro Vancouver were included in the final analysis with nineteen municipalities (City of Langley and Township of Langley were combined; City of North Vancouver and District of North Vancouver were combined), and one “Indigenous Reserves” category that included Burrard Inlet 3, Capilano 5, Coquitlam 1, Katzie 1, Katzie 2, and Seymour Creek 2 First Nation Reserves. DAs in Electoral Area A and Indigenous Reserves were not geographically adjacent to each other but still included in the analysis. 87 DAs with population density below the bottom 2.5 percentile (101 people/ km^2) from the original data of 3444 were removed. The excluded data represented areas with a large land area with few residents or with non-residential landmasses (mountain or agricultural land); therefore, those DAs did not apply to the "15-Minute City" analysis. The overall population density in each municipality ranged from 117 in Belcarra to 5427 people/km^2 in Vancouver with an average of 2318 people/ km^2 per DA.

This section discussed the overall access of Metro Vancouver to all six categories of services then summarized the access to five to two services and finally discussed the access to individual services. The result described the variability of access distribution by municipality, population density, age and situational deprivation as a proxy for socioeconomic status. The default walking speed in this section was 3.6 KM/H unless stated otherwise because it represents the most conservative estimate of walking speed that included people of all ages and abilities, particularly those between ages 0 to 14 and above 65.

3.2 Overview of Access to Services

Overall, only 736 DAs (22%) in Metro Vancouver were considered "15-Minute Cites" as all six categories of services were reachable within 15 minutes of walking at 3.6 KM/H, which equates to about 23% of the total population. Based on a walking speed of 4.8 KM/H, 1308 DAs (39%) in Metro Vancouver were considered "15-Minute Cities" with all six categories reachable within 15 minutes of walking, which was a 78% increase in the number of DAs accessible (Figure 4). 99.9% of DAs in Metro Vancouver had access to at least one service (could be healthcare, grocery stores, greenspace, education, community centre or transit stops) whereas only 23% of DAs had access to all six (Figure 4). The overall trend showed that population density increased as the number of services reached increased. This meant more densely populated areas had higher access compared to less densely populated areas of Metro Vancouver (Figure 5).

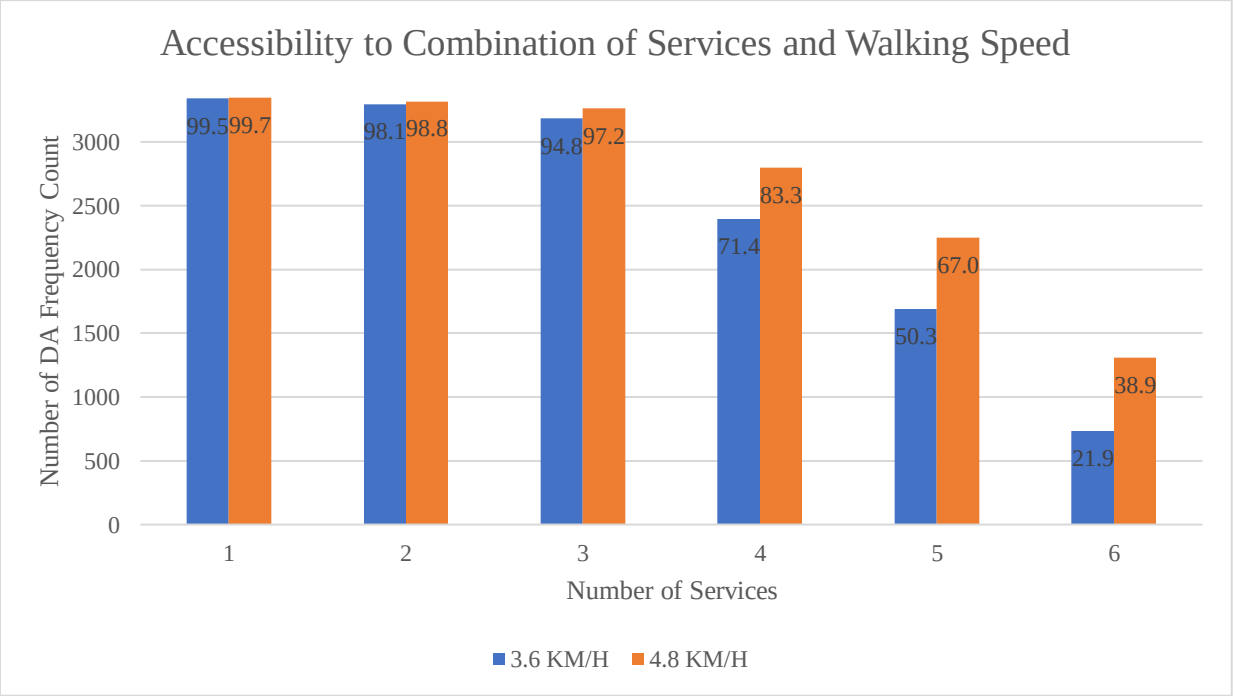

Figure 4 Access to different number of services within 15 minutes of walking in Metro Vancouver (3.6 and 4.8 KM/H)

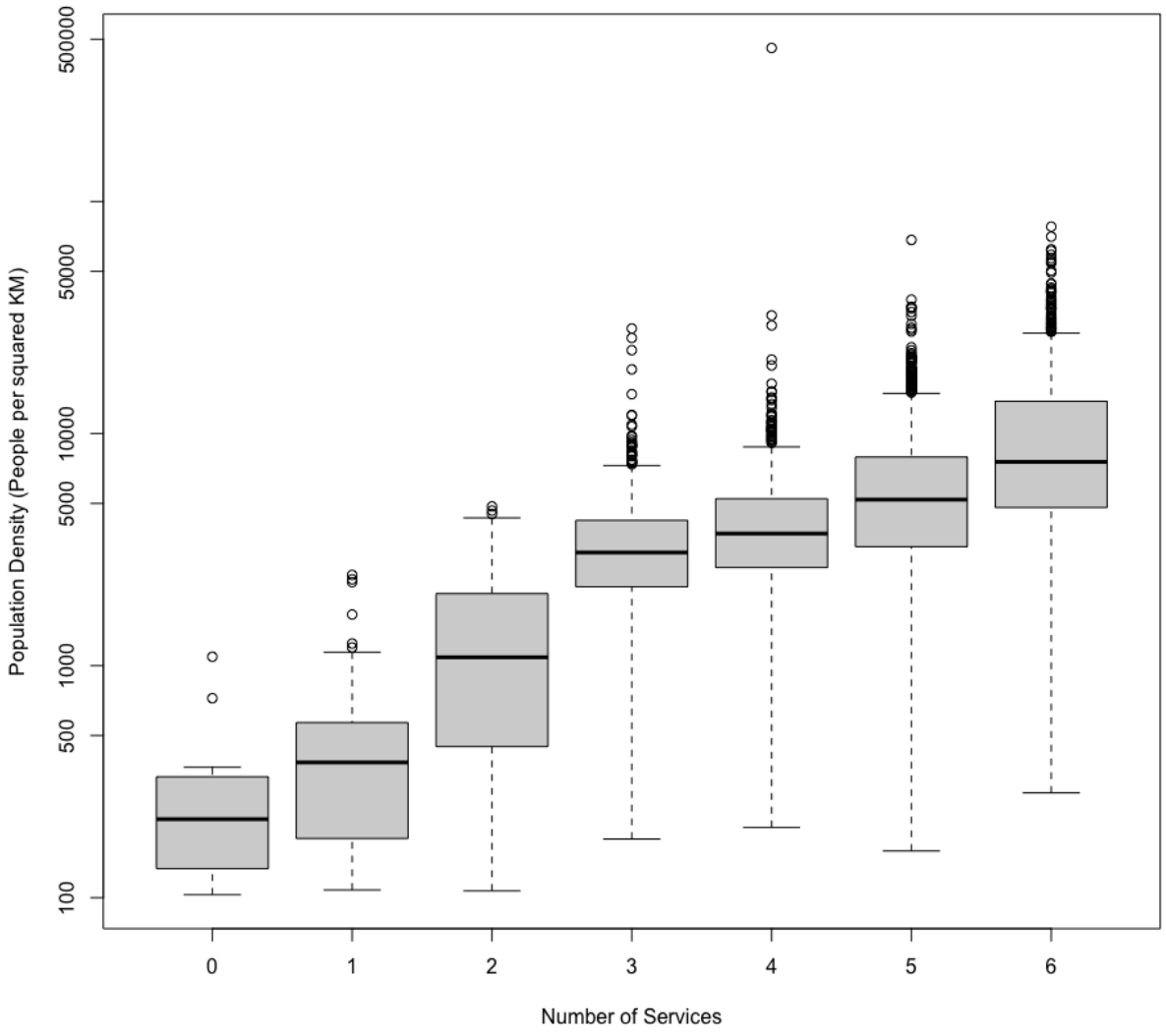

Figure 5 Population density distribution of access to different combinations of services in Metro Vancouver based on walking speed of 3.6 KM/H for fifteen minutes of walking

3.2.1 15-Minute City – All 6 categories (Walking Speed 3.6 KM/H)

Out of the 22% of DAs that were considered "15-Minute City" neighbourhoods, the City of Vancouver had the greatest number of DAs (41%) accessible to all six categories. Vancouver was also the most densely populated municipality with 5427 people/ KM^2. All other municipalities had below 15% of DAs accessible to all six services regardless of population density except New Westminster (23%), Burnaby (25%), North Vancouver (30%), and

Indigenous Reserves (23%) (Figure 6, 7 and Table 9). White Rock and Richmond, with higher-than-average population density, only had 11% and 12% of DAs accessible to all six categories of services respectively. In Belcarra, Bowen Island, Lions Bay, Anmore, Tsawwassen and Electoral Area A, none of the 23 DAs in these municipalities had access to all six services.

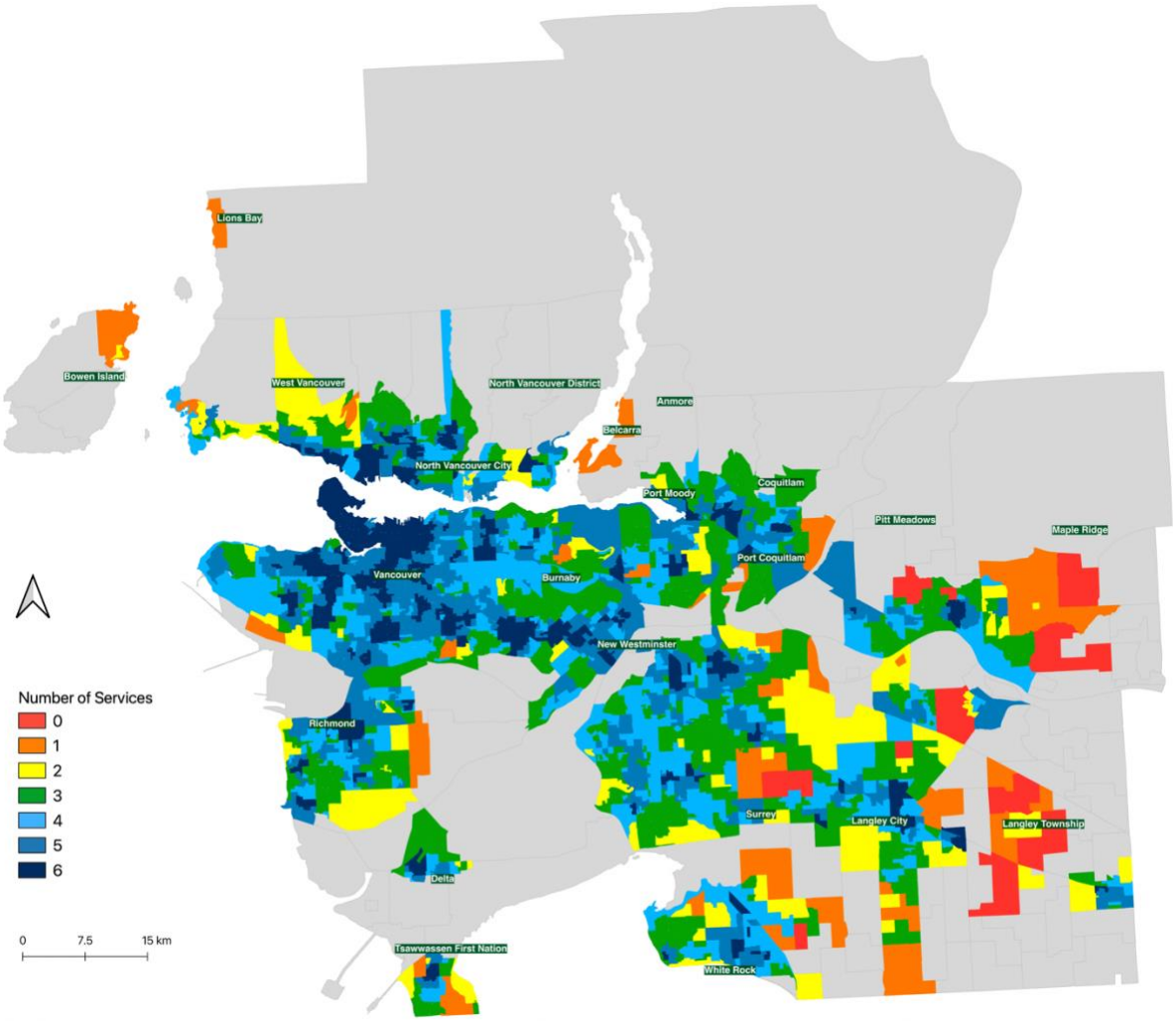

Figure 6 Number of services reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver

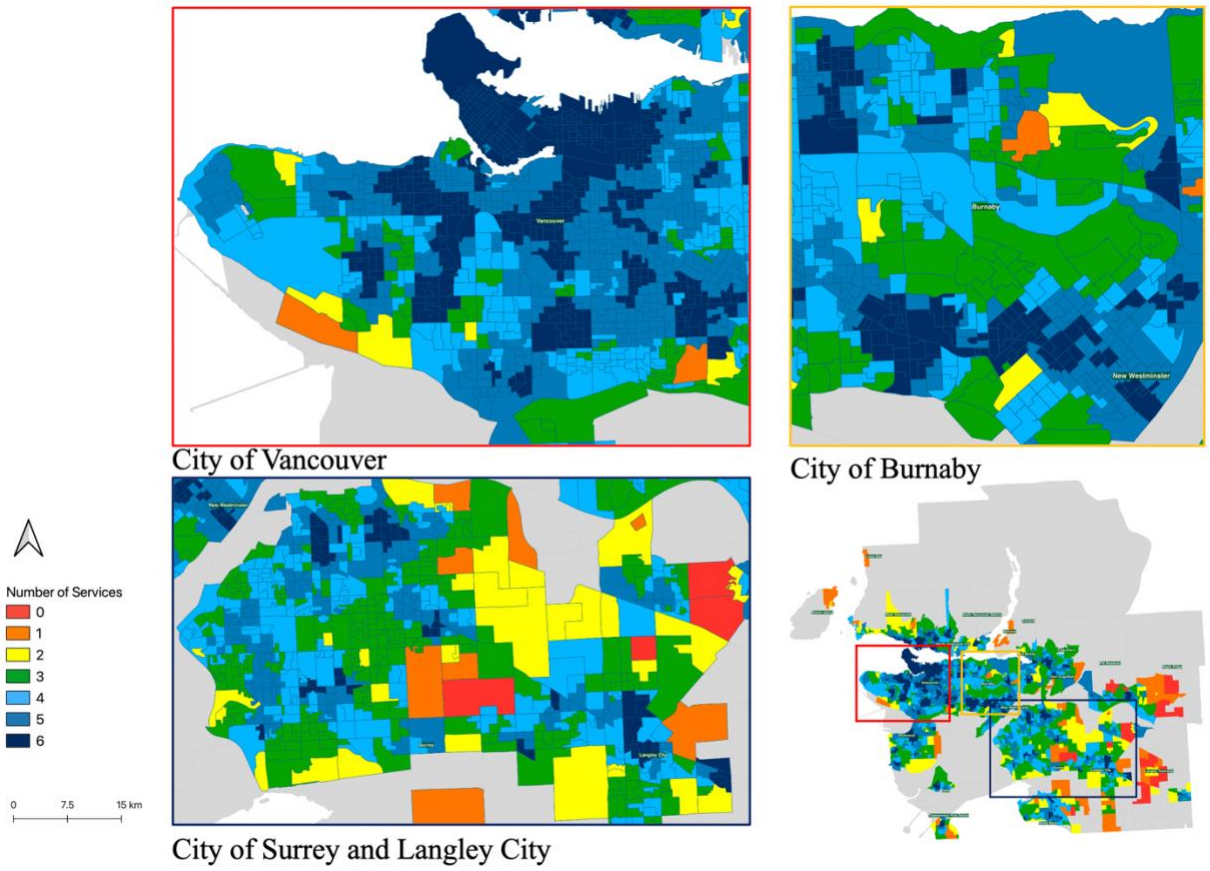

Figure 7 Number of services reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

Table 9 Number and percent of DAs with access to number of services in each municipality

		Number of Services Reached						
Municipality	# of DA	0 (N, %)	At Least 1	At Least 2	At Least 3	At Least 4	At Least 5	All 6
Belcarra	1	0	1 (100)	0	0	0	0	0
Bowen Island	2	0	2 (100)	1 (50)	0	0	0	0
Lions Bay	2	0	2 (100)	0	0	0	0	0
Anmore	1	0	1 (100)	1 (100)	1 (100)	0	0	0
Tsawwassen	1	0	1 (100)	1 (100)	0	0	0	0
Maple Ridge	110	5 (5)	105 (96)	97 (88)	92 (84)	49 (45)	28 (26)	9 (8)
Langley	177	9 (5)	168 (95)	157 (89)	141 (80)	91 (51)	49 (28)	22 (12)
Indigenous Reserves	13	0	13 (100)	10 (77)	7 (54)	5 (39)	4 (31)	3 (23)
West Vancouver	74	0	74 (100)	72 (97)	54 (73)	34 (46)	27 (38)	7 (9)
Electoral Area A	16	0	16 (100)	16 (100)	16 (100)	14 (88)	8 (60)	0
Pitt Meadows	20	0	20 (100)	20 (100)	20 (100)	17 (85)	11 (66)	1 (5)
Port Coquitlam	82	0	82 (100)	80 (98)	80 (98)	42 (51)	29 (35)	8 (10)
Surrey	585	2 (<1)	583 (99.7)	573 (98)	541 (93)	347 (59)	178 (30)	46 (8)
Delta	163	0	163 (100)	161 (99)	151 (93)	90 (55)	50 (31)	13 (8)
Port Moody	39	0	39 (100)	39 (100)	38 (98)	18 (46)	14 (36)	3 (8)
North Vancouver	207	0	207 (100)	207 (100)	205 (99)	14369)	108 (52)	62 (30)
Coquitlam	182	0	182 (100)	180 (98)	176 (97)	96 (52)	46 (25)	19 (10)
Richmond	243	0	243 (100)	242 (98)	235 (97)	146 (60)	87 (36)	30 (12)
Burnaby	321	0	321 (100)	320 (99)	315 (98)	256 (79)	173 (54)	79 (25)
White Rock	35	0	35 (100)	35 (100)	34 (97)	33 (94)	23 (66)	4 (11)
New Westminster	90	0	90 (100)	90 (100)	90 (100)	87 (97)	69 (77)	21 (23)
Vancouver	993	0	993 (100)	992 (99.9)	988 (99.5)	930 (94)	784 (79)	409 (41)
Overall	3357	16 (<1)	3340 (99.5)	3294	3184 (95)	2398 (71)	1688 (50)	736 (22)

3.2.2 Impact of Walking Speed

The faster walking speed of 4.8 KM/H increased access to six essential services by 78% in terms of the number of DAs (Figure 8). However, the extent of the increase varied between municipalities based on their characteristics. Surrey had the largest increase in absolute numbers of DAs where an additional 71 DAs were within the "15-Minute Cites" based on the faster walking speed. The percentage point change of "15-Minute City" DAs was also compared between the two walking speeds because each municipality has different numbers of DAs.

The greatest percentage points increase was in New Westminster and Pitt Meadows (both 40% increase), where 63% and 45% of their DAs respectively were considered "15-Minute Cities" (Figure 8). Most municipalities had at least a 6% increase due to an increase in walking speed

except Anmore, Belcarra, Bowen Island, Lions Bay, Tsawwassen and Electoral Area A which did not have any changes.

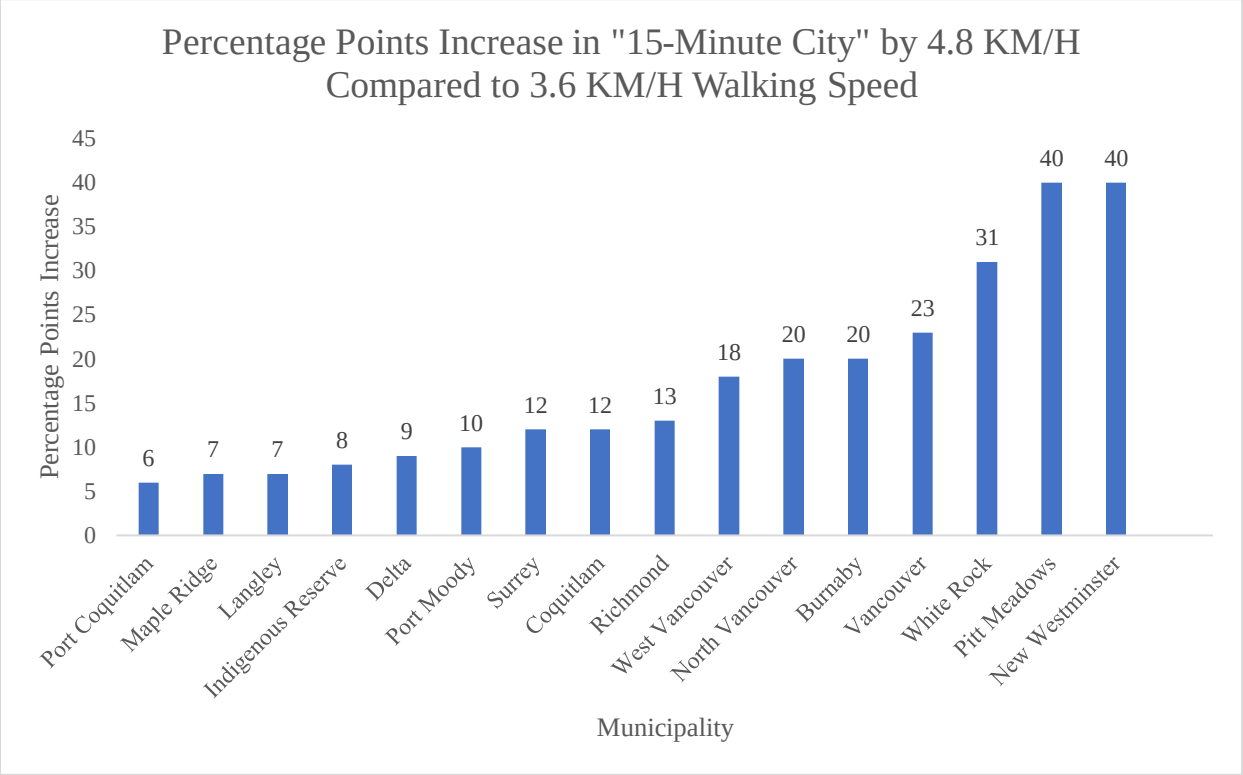

Figure 8 Percentage point increase in the number of DAs within the "15-Minute City" between 3.6 to 4.8 KM/H walking speed (excluding Anmore, Belcarra, Bowen Island, Lions Bay, Electoral Area A, and Tsawwassen that had no change in the number of DAs between the two walking speeds)

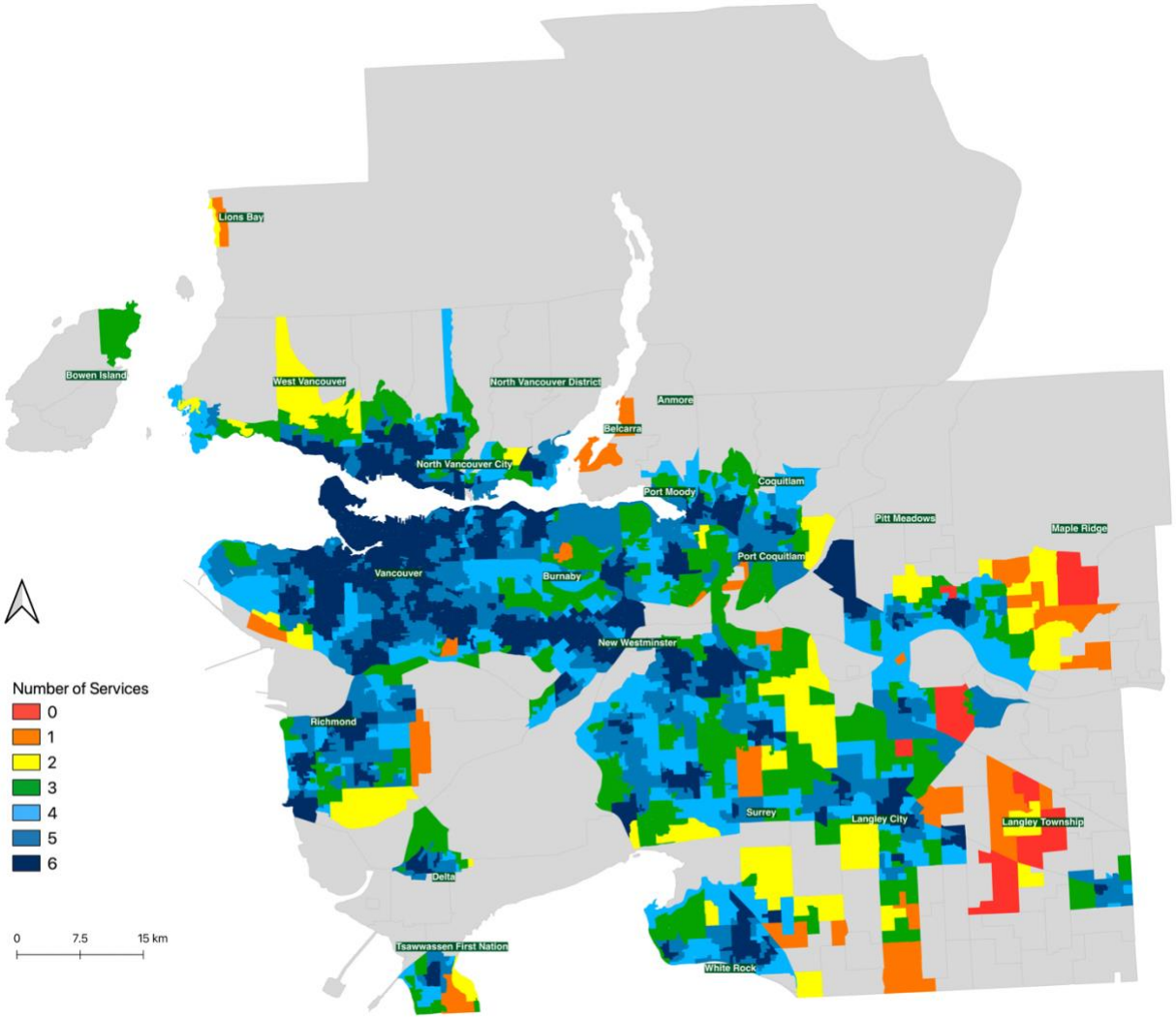

Figure 9 Number of services reached within 15 minutes of walking (4.8 KM/H) in Metro Vancouver

3.2.3 Summary of Access between Five to Two Services

There was a 29% increase in the percentage of DAs having access to at least five services compared to all six while a subsequent increase in the number of DAs decreased when looking at access to four to two categories. The overall trend of access between at least five to two services showed a general increase in access as population density increases based on different municipalities (Figure 10). However, some municipalities with smaller population densities still had higher access than those with larger population densities. Using access to at least five

services as an example, Electoral Area A and Pitt Meadows had smaller population densities than Port Coquitlam, Surrey, Delta, and Port Moody. Nonetheless, Electoral Area A and Pitt Meadows had more than 50% of DAs having access to at least five service categories, which is more than 20% points higher than that of Port Coquitlam, Surrey, Delta, and Port Moody. Similarly, North Vancouver had a smaller population density, but higher access compared to those of Coquitlam and Richmond, which both had higher population density (Figure 10). This trend mentioned where small population density municipalities had better access was also observed when examining access to other numbers of services.

As the number of services reached decreases from five to two, the number of DAs accessible generally increased because the access can be a combination of any of the six service categories. However, several municipalities with low population density still had low access. For example, none of the DAs in Belcarra, Bowen Island, Lions Bay and Tsawwassen had access to at least three categories. When decreasing the number of services to two, Belcarra and Lions Bay still had none of their DAs accessible while Bowen Island, Maple Ridge, Langley and Indigenous Reserves still had below 90% of their DAs accessible, while all other municipalities had above 90% of their DAs accessible to at least two services (Table 10). Out of all 3357 DAs, sixteen DAs had no access to any of the six service categories within 15 minutes of walking and they were in Maple Ridge, Langley, and Surrey. Maple Ridge and Langley had a below-average population density of around 950 people/KM^2 while Surrey had a relatively higher population density of around 1600 people/KM^2.

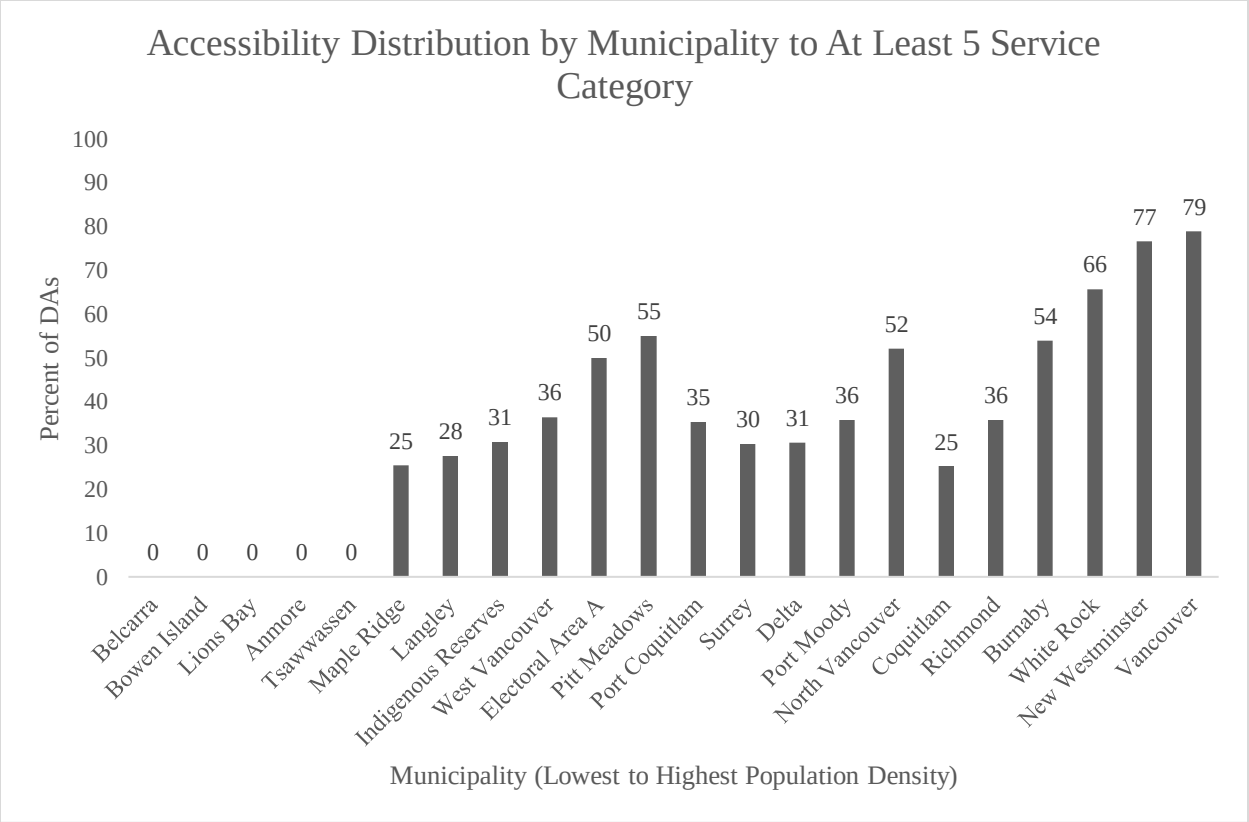

Figure 10 Percent of DAs accessible to at least five service categories within 15 minutes of walking (3.6 KM/H) based on municipality

3.3 Access to Individual Services

More than 99% of DAs in Metro Vancouver had access to at least one of the six service categories. The most accessible services were greenspace, followed by transit stops, education facilities, healthcare facilities, and community centres. The following section described the results for each service.

Overall, 99% of DAs had access to greenspace within 15 minutes of walking. Access to at least one public transit stop was worse than greenspace but 97% of DAs had access to at least one public transit, and 96% had access to an education service. Compared to greenspace, public

transit stops and education centres, there was considerably less access to healthcare facilities, grocery stores and community centres where the percentage of DAs with access were 65%, 44% and 36%, respectively (Table 10). None of the DAs in Belcarra, Bowen Island, Lions Bay, Anmore and Tsawwassen had access to a healthcare facility or grocery store within 15 minutes of walking (Table 10).

Table 10 Access to individual services within 15 minutes of walking (3.6 KM/H) by municipality in Metro Vancouver

Municipality	# of DA	Greenspace (N, %)	Public Transit	Education	Healthcare	Grocery Stores	Community Centres
Belcarra	1	0	1 (100)	0	0	0	0
Bowen Island	2	1 (50)	2 (100)	0	0	0	0
Lions Bay	2	1 (50)	0	1 (50)	0	0	0
Anmore	1	1 (100)	0	1 (100)	0	0	1 (100)
Tsawwassen	1	1 (100)	1 (100)	0	0	0	0
Maple Ridge	110	96 (87)	98 (89)	97 (88)	40 (36)	29 (26)	20 (18)
Langley	177	161 (91)	150 (85)	153 (86)	77 (44)	33 (19)	54 (31)
Indigenous Reserves	13	13 (100)	10 (77)	7 (54)	5 (38)	4 (31)	3 (23)
West Vancouver	74	72 (97)	72 (92)	56 (76)	30 (41)	21 (28)	17 (23)
Electoral Area A	16	16 (100)	16 (100)	16 (100)	14 (88)	8 (50)	0
Pitt Meadows	20	20 (100)	19 (95)	20 (98)	11 (55)	5 (25)	14 (70)
Port Coquitlam	82	82 (100)	80 (98)	80 (96)	35 (43)	30 (27)	14 (17)
Surrey	585	582 (99)	549 (94)	560 (94)	311 (53)	149 (25)	117 (20)
Delta	163	163 (100)	155 (95)	154 (94)	77 (47)	31 (19)	48 (29)
Port Moody	39	39 (100)	38 (97)	38 (97)	17 (44)	8 (21)	11 (28)
North Vancouver	207	207 (100)	206 (99)	205 (99)	117 (57)	102 (49)	95 (46)
Coquitlam	182	182 (100)	178 (98)	175 (96)	86 (47)	40 (22)	38 (21)
Richmond	243	242 (99)	237 (98)	241 (99)	124 (51)	91 (37)	48 (20)
Burnaby	321	321 (100)	319 (99)	315 (98)	236 (75)	155 (48)	118 (37)
White Rock	35	35 (100)	35 (100)	34 (97)	31 (89)	18 (51)	11 (31)
New Westminster	90	90 (100)	90 (100)	90 (100)	81 (90)	35 (39)	61 (68)
Vancouver	993	990 (99)	991 (99)	987 (99)	879 (89)	727 (74)	522 (53)
Overall	3357	3315 (99)	3247 (97)	3230 (96)	2171 (65)	1486 (44)	1192 (36)

The spatial distribution of access between the six individual services followed similar trends where access to any of the six services decreased from less urban areas first, which were more in the east and south side of Metro Vancouver. Areas with consistently low access were Maple Ridge, Surrey, and Langley (Figure 11). For services with low access such as grocery stores and community centres, most areas in Vancouver and central areas of other municipalities still had

access to these services individually, which highlighted that the spatial distributions of these services were not equally accessible within Metro Vancouver.

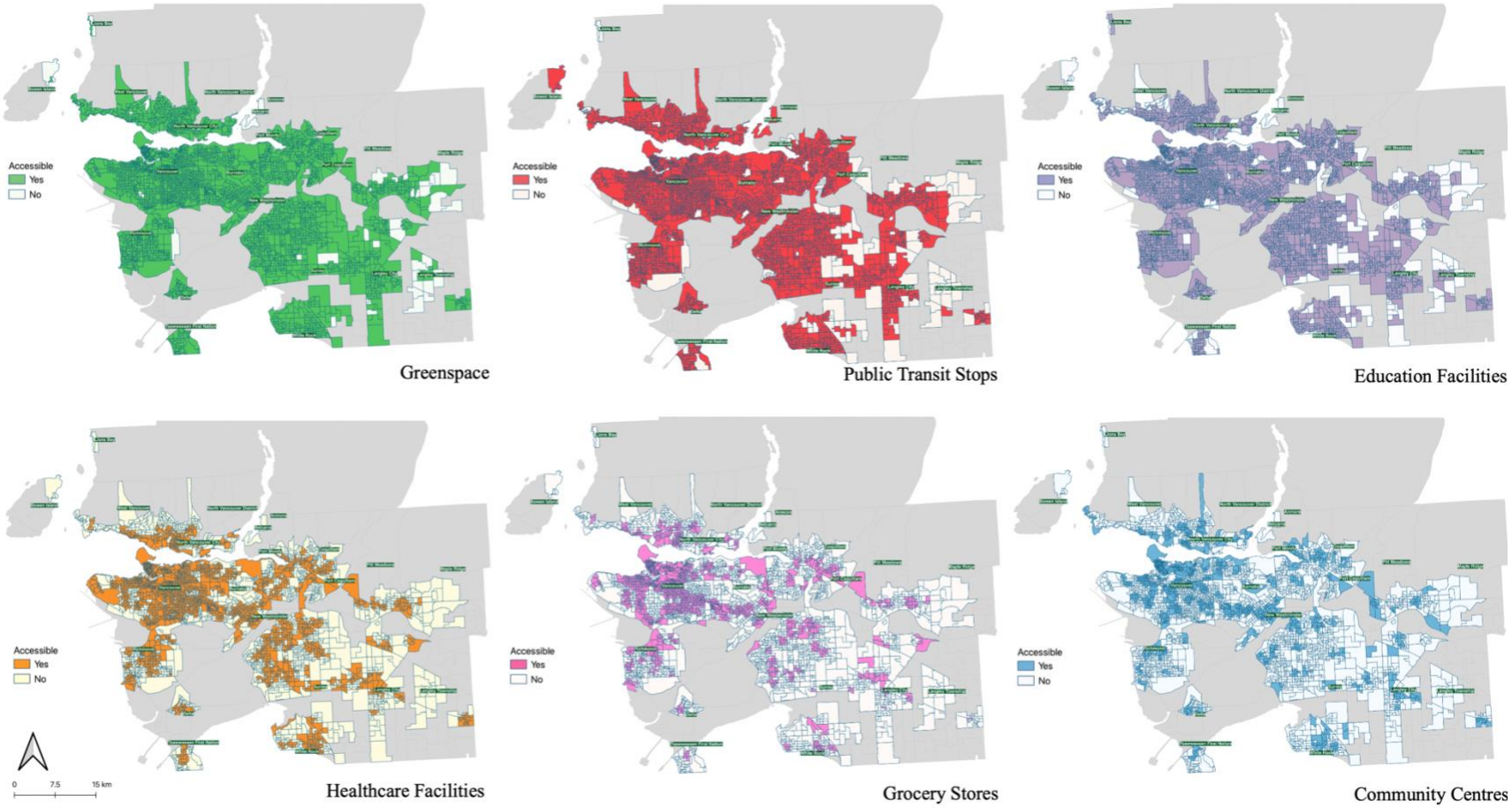

Figure 11 Access to individual essential services in Metro Vancouver within 15 minutes of walking (3.6 KM/H)

3.4 Socioeconomic Index- Situational Deprivation

In addition to municipality and population density, situational deprivation differences were also analyzed to assess the level of equity in access to essential services across Metro Vancouver. In terms of the spatial distribution of situational deprivation, areas with the least amount of situational deprivation included Vancouver and areas of West and North Vancouver. Notably, Anmore, Belcarra, Bowen Island, Lions Bay and Tsawwassen, which had the poorest access, all had the least amount of situational deprivation. This showed that decreased situational deprivation was correlated with decreased access for these municipalities. Clusters of the highest situational deprivation were seen in North Surrey, East Vancouver and some parts of Richmond, Maple Ridge and Langley. Surrey and Maple Ridge both had 8% of DAs as "15-Minute City" while Richmond and Langley had 12%, which were significantly lower than Vancouver with 41% of DAs as "15-Minute Cites". Indigenous Reserves also had the highest proportion in the most situationally deprived category (62% of DAs) compared to other municipalities of Metro Vancouver. However, 23% of DAs on Indigenous Reserves had access to all six services within 15 minutes of walking, which was the same as New Westminster as the fourth most accessible municipality.

Overall, "15-Minute City" neighbourhoods or having access to all six services had the highest proportion in the least situationally deprived category (27%) compared to other more situationally deprived categories. The second highest was in the most situationally deprived group with 23% of DAs in this category. The lowest proportion of "15-Minute Cites" was in the second most situationally deprived category, which indicated that a medium level of situational deprivation had the poorest access to all six essential services. Access to other numbers of

services had similar proportions between each situational deprivation category with the exception that access to at least four services increased as situational deprivation increased (Figure 12).

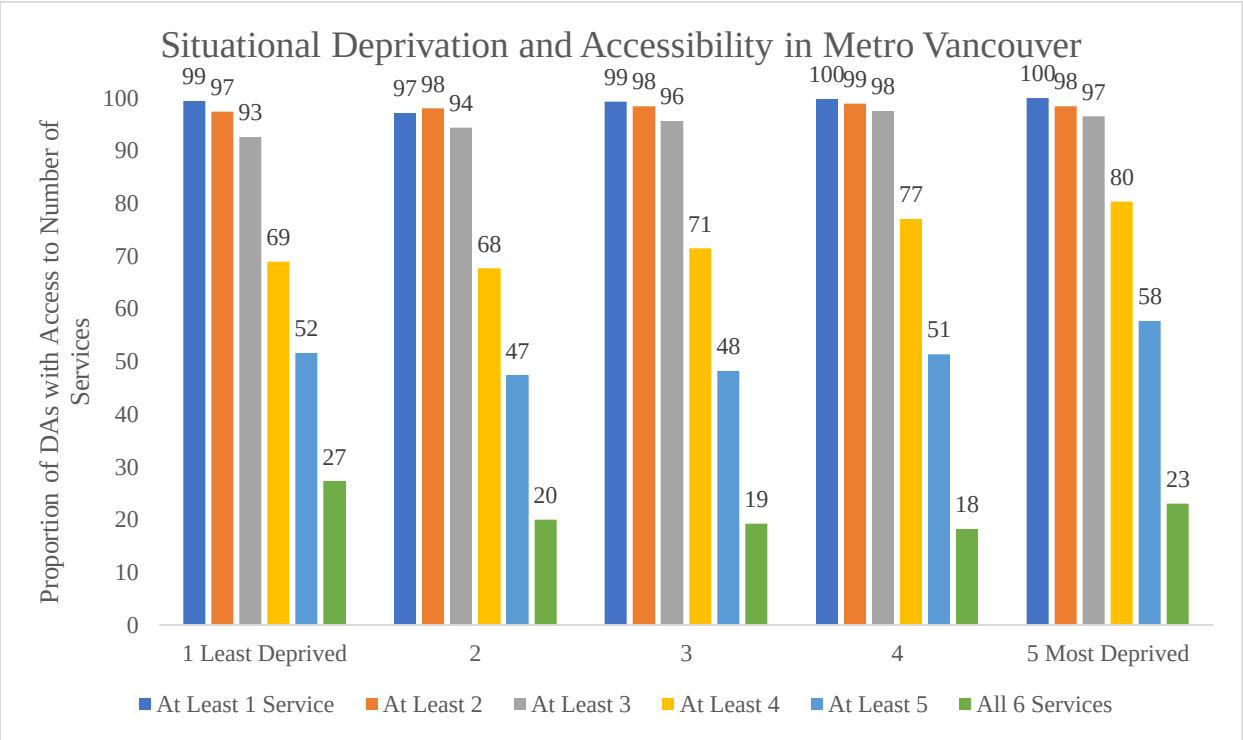

Figure 12 Access to number of services within 15 minutes of walking (3.6 KM/H) in Metro Vancouver based on situational deprivation (Canadian Index of Multiple Deprivation, 2016)

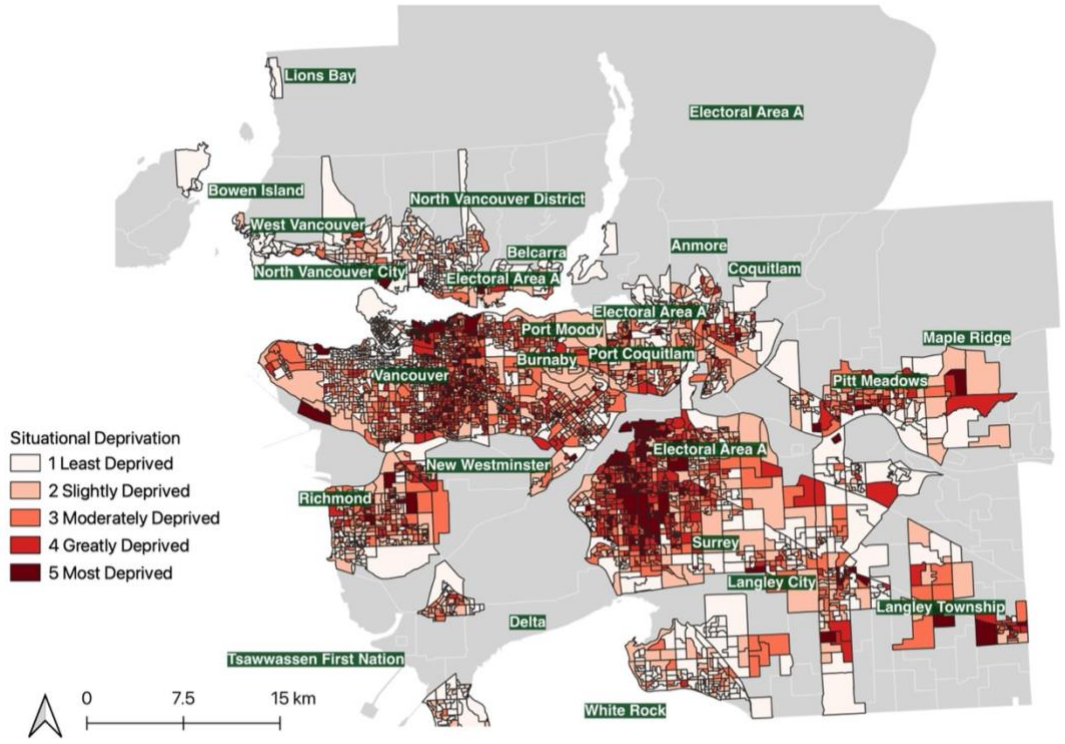

Figure 13 Distribution of situational deprivation in Metro Vancouver based on the Canadian Index of Multiple Deprivation (2016)

3.5 Age

In addition to situational deprivation, the neighborhood population age distribution was another factor applied to examine the equity of access to essential services in Metro Vancouver. Based on the 2016 Statistics Canada Census Data, the mean of the Metro Vancouver population was 41.4 years. Population proportions of different age categories were compared between "15-Minute Cites" (having access to all six services) and non-"15-Minute Cites". "15-Minute Cites" had 28% of people between the ages 0 to 14 and above 65 while non-"15-Minute Cites" had 32% of the population between the ages 0 to 14 and above 65. While the difference in age proportions between "15-Minute Cites" and non-"15-Minute Cites" was not statistically significant, there was still an indication that areas with a lower proportion of younger and older populations had

better access to essential services compared to areas with higher proportions of younger and older people. This disparity was primarily driven by the proportion in the 0 to14 age group.

Spatially, areas with clusters of people between ages 0 to 14 and above 65 were in Tsawwassen, White Rock, Langley, West Vancouver, and within Indigenous Reserves (Figure 14). Among these areas, Tsawwassen had the poorest access where none of its DAs had access to all six essential services. White Rock and Langley also had only 11% and 12% of its DAs accessible to all six services. While both West and North Vancouver had a high proportion of younger and older populations, West Vancouver only had 9% of its DAs accessible while North Vancouver had 30% of DAs accessible to all six services.

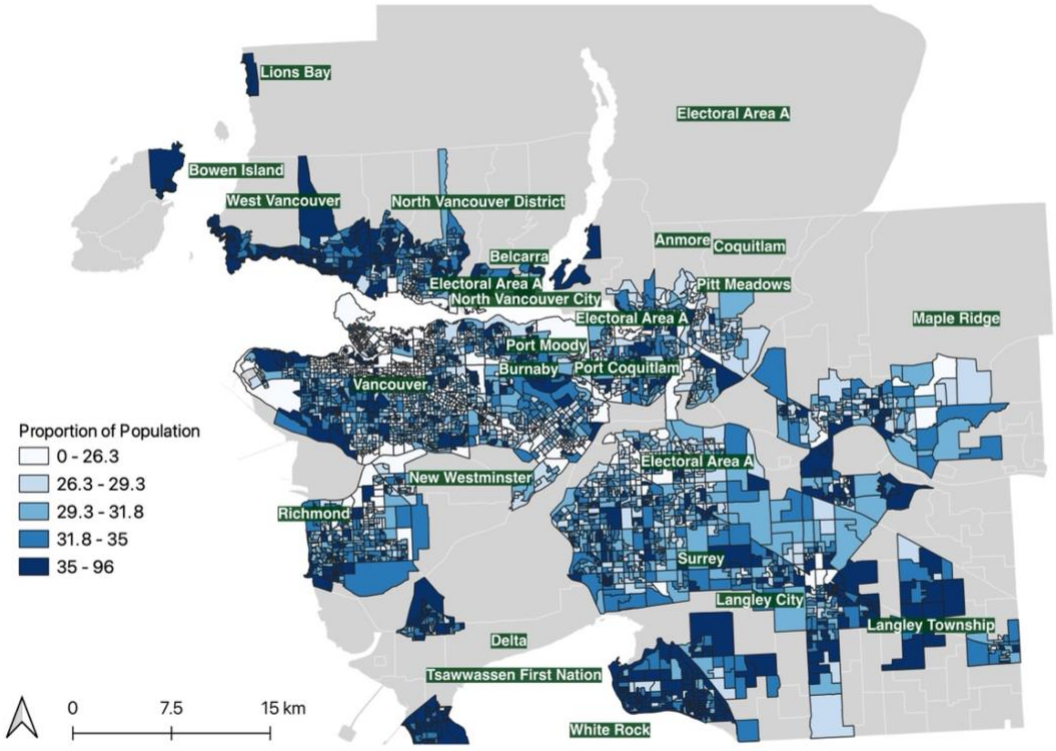

Figure 14 Distribution of the proportion of the population who are aged 0-14 or 65+ in Metro Vancouver

3.7 Summary of Results

Only 22% of DAs in Metro Vancouver had access to all six essential services (greenspace, public transit, education centres, healthcare facilities, grocery stores and community centres) within 15 minutes of walking at a speed of 3.6 KM/H. Greenspace was the most commonly accessible service, while community centres were the least commonly accessible. The faster walking speed of 4.8 KM/H increased the number of DAs with access to all six services by 17 percentage points. The City of Vancouver most resembled a "15-Minute City" out of all the Metro Vancouver municipalities with 41% of its DAs having access to all six essential services. In general, neighbourhoods that were "15-Minute Cities" had two times the population density, a lower proportion of the population ages 0 to 14, and the highest proportion of people in the least situationally deprived category compared to DAs that were not "15-Minute City" neighbourhoods.

Chapter 4: Discussion

4.1 "15-Minute City" in Metro Vancouver and Other Cities

Since the "15-Minute City" concept was first popularized in 2016, it has been adopted into urban planning strategies around the world such as the *20-Minute Neighbourhoods Plan* in Portland, the *Land Transport Master Plan 2040* in Singapore, and post-pandemic recovery strategies such as *Paris En Commun* and *Milano 2020* (Wiewel & Kafoury, 2012; Land Transport Authority, n.d.; Pisano, 2020). This study was part of the of the "Pathways to Equitable Healthy Cities" global partnership and applied the "15-Minute City" concept to Metro Vancouver, one of the most economically vibrant and culturally diverse cosmopolitan centres in Canada. To the author's knowledge, this was the first study in Canada and one of the first studies in the world to quantitatively evaluate the distribution of equity of access to various essential services based on the "15-Minute City" concept.

Overall, only 22% of DAs in Metro Vancouver were considered "15-Minute City" neighborhoods by having access to healthcare, education, greenspace, grocery store, community centre and public transit services within 15 minutes of walking. This corresponded to 549,843 people (23% of the total population) living within "15-Minute Cites" while 13,491 people (0.5 % of the total population) had no access to any of the six services. Spatially, the City of Vancouver had the largest proportion of DAs (41%) with access to all six services compared to all other municipalities in Metro Vancouver. This result was expected since Vancouver was the most densely populated city in the region. Access to essential services was not equitably distributed – rather it was patterned by situational deprivation and by age. "15-Minute Cites" tended to be in areas with lower proportions of people between aged 0 to 14. Age has been associated with

changes in walking speed where older people tend to walk slower on average whereas young to middle-aged adults walk faster on average (Knoblauch et al., 1996). Literature in the past had also shown that many essential services such as public transit favoured young adults and excluded the elderly population (Papa et al., 2018; Ryan et al., 2016). They also tended to be in areas with the least amount of situational deprivation, based on an index that included a lower proportion of Indigenous individuals, people without high school diplomas, dwellings needing major repairs, low-income populations, and single-parent families.

Comparing the "15-Minute City" result in Metro Vancouver to other "15-Minute City" studies, a similar study that utilized the "15-Minute City" concept was conducted in Shanghai, China; however, this analysis included a wider range of services including cultural, entertainment venues, financial services, and elderly care (Weng et al., 2019). In Shanghai "15-Minute Cites" were concentrated in central or urban areas while rural areas had poorer access to all the amenities. This was consistent with the results for Metro Vancouver as access increased in urban cores such as the City of Vancouver and decreased in more suburban areas (Figure 7). In terms of age, Weng et al., (2019) also found that senior and adult concentrated communities were more walkable to services whereas children concentrated in areas had lower walkability.

Other "15-Minute City" studies also examined the distribution of services by socioeconomic factors. In a post-pandemic scenario analysis in Bogotá, Colombia, education and healthcare services were concentrated in wealthier neighbourhoods with a higher concentration of employment and service opportunities (Guzman et al., 2017). A "15-Minute City" study in Chicago that evaluated access to healthcare, parks, grocery store, education and transit found that

only 8% of Chicago neighbourhoods had access to all the defined services and that neighbourhoods with high access were predominately white with low rates of unemployment and high rates of education (Bright, 2021). The results of these two studies were comparable to Metro Vancouver since "15-Minute Cities", or increased access to services, were more concentrated in areas with the least amount of situational deprivation that included income and other socioeconomics factors.

Other studies did not directly apply the concept of "15-Minute City" but examined access to multiple essential services. In New Zealand, 80% of people could walk to healthcare facilities in less than ten minutes, which was significantly more accessible than in Metro Vancouver since only 65% of DAs in Metro Vancouver had access to one healthcare facility (Vannier et al., 2020). The study also found an urban-rural gradient in access where suburban areas were most deprived of access compared to urban areas thus leading to social inequity. A study one decade earlier in New Zealand had similar results where spatial deviation from central to rural areas led to fewer services availability (Pearce, 2006). The results of these two studies resonated with the observation in Metro Vancouver where access is concentrated in urban areas and decreased in less urban areas.

Other studies of a single service such as a future scenario mapping of healthcare in Surrey, BC estimated that 27,000 more people (50% seniors) would not have access to a hospital under thirty minutes of public transit or walking in 2022. They predicted that seniors above the age of 65 would move to more rural and thus less connected communities in the future; therefore having lower access to walk-in clinics and hospitals compared to youth under the age of 20 (Mayaud et

al., 2018). While only access to healthcare was examined in this study, the result was significant as it indicated that seniors in Surrey, a Metro Vancouver municipality, may experience disproportionately less access compared to the younger population.

In Montreal, a similar study showed that lower socioeconomic status in self-defined neighbourhoods was associated with lower access to all twelve services analyzed such as grocery, education, social services and healthcare (Vallée et al, 2019). Different from this study, they used maternal education as the proxy for socioeconomic status. However, the result was comparable to this study since access in Metro Vancouver was better in neighbourhoods with the least amount of situational deprivation as a proxy for socioeconomic status. Other studies of access in Korea (Yhee et al., 2021) and Italy (Boncinelli et al., 2015; Gaglione et al., 2022) used more complex measures such as an accessibility index or evaluating access as part of the quality of life instead of travel distance or cumulative opportunity, which made them difficult to compare to this study.

4.2 Explanation of Observed Patterns

The observed differences in access to essential services in Metro Vancouver could be broadly attributed to two factors. First, people might experience poor access because they live in neighbourhoods with poor connectivity to services. Second, there may not be enough services in these neighborhoods. Theoretically, individuals can choose to relocate to areas with high access to meet their demands. However, such mobility is often hindered by major economic constraints and the lack of housing and rental affordability in Metro Vancouver. According to the International Monetary Fund (2021), Canada had the third-largest increase in real housing prices in the world in 2020, while the City of Vancouver, the most accessible municipality, arguably

has some of the worst housing affordability in the world. Therefore, the lack of ability and mobility for people to move to areas with high access in Metro Vancouver has detrimental effects on people's life opportunities, economic prosperity, quality of life and well-being. Therefore, government policies at all federal, provincial, and municipal levels have a great influence on bringing services to people and communities to ensure everyone has access to basic and essential services. The six services in this study spanned public (e.g., community centre), private (e.g., grocery store), or mixed-type services (e.g. healthcare services) and thus, the decision-making bodies that determine their location differ.

For example, the lack of access to community centres, the least accessible service type, may be attributed to the lack of physical infrastructure. The physical location and building of these services were designated by each municipality with elected commissioners from neighbourhoods within the municipality. For example, the City of Vancouver and its Park Board operate jointly as the "Community Centre Associations" to set policies, allocate financial resources, design parks, community centre buildings, other facilities located on such lands, and recreational programs within each infrastructure (The Strategic Action Group, 2016; City of Vancouver, 2018). Therefore, decision-makers at the municipal level had a significant influence on where and when community centres were built.

While decisions regarding public community centres involved municipalities, the location decisions regarding grocery stores were more complicated. Overall, the food store locations in Metro Vancouver are influenced by two major factors: zoning bylaws and commercial decisions. The zoning regulations in Metro Vancouver can be regional or municipal with significant

implications for where commercial businesses like grocery stores can be located. People who were involved in designing zoning regulations may be land-use planners, legislators, and developers, who determine which areas may be suitable for commercial development and economic growth (Black et al., 2011). When planning the distribution of commercial spaces, zoning bylaws are not neutral as policymakers may designate specific areas based on their own economic and developmental interests, which further perpetuated inequity within the city (Bates & Santerre, 1994). For instance, wealthy neighbourhoods might want to preserve their single-unit housing value and thus advocate to keep multi-purpose commercial venues and supermarkets out of their neighbourhoods, which reflected the exclusionary interest of certain zoning bylaws. As a result, this study and studies in other cities found that most situationally deprived or socioeconomically distressed neighbourhoods have better access to food retailers and grocery stores (Sadler et al., 2011; Smith et al., 2010). As a response to zoning bylaws, commercial managers, entrepreneurs, and developers might subsequently locate their grocery stores in areas with more apartment buildings and foot traffic, which might be lower-income areas with more proportions of visible minorities based on the economic analysis of a region's demographic, consumer patterns and population density (Black et al., 2011).

Another service directly influenced by government regulations was the provision of greenspaces, which was the most accessible service in Metro Vancouver based on this study. A Surrey study surveyed residents, managers and politicians on factors influencing the availability of urban greenspace, which revealed that the development of greenspace was directly driven by *Metro Vancouver Regional Growth Strategy* mandates, local municipal policy (i.e., Official Community Plans), land speculation, property values, economic constraints, and community expectations,

while indirectly related to governance structure, culture and resources (Boulton et al., 2020). In other words, service access and availability were shaped by complex forces spanning municipal administration, local government, property development and public opinion. While Boulton et al. (2020) examined the factors influencing the creation of greenspace, one can argue that the factors mentioned above may also impact other public and private services such as healthcare, education and public transit. Therefore, zoning bylaws and government policies had significant influence over where services were located.

In addition to government policies and actions, transportation via road network and public transit were also important factors for access. For more suburban municipalities like Surrey and Langley, "15-Minute City" neighbourhoods clustered around the Fraser Highway and access decreased with increasing distance from the highway (Figure 6). This trend is consistent between Surrey, Langley City and Aldergrove within Langley Township; however, the middle area between Langley City and Aldergrove had significantly less access with only two DAs having access to two services. This observation was consistent with a study of Canadian urban sprawl patterns that suggested that current road network connectivity and development in suburban Canada were not equitably distributed across suburban areas and lagged behind municipal development (Barrington-Leigha & Millard-Ballb, 2014). Furthermore, the road connectivity issues were also observed when several DAs in Surrey, Langley and Tsawwassen were within fifteen minutes of certain service catchments according to Euclidean distance but were not considered accessible within 15 minutes because there was no connected road infrastructure or walking routes were blocked by other infrastructures thus increasing walking time due to detours.

While access was influenced by the density and connectivity of road networks, access to public transit was another major factor in shaping people's access. While 97% of DAs in Metro Vancouver had access to at least one public transit stops, this did not guarantee the suitability of public transportation as it does not reflect transit routing, frequency and capacity. Public transit decision-making sits regionally with TransLink, which also has a significant influence on where and how services are located (TransLink BC, 2012). The collective influence of transportation and roadwork was also related to government policy and mandates, thus showing its importance when deciding where services were located.

4.3 Importance of "15-Minute City"

While people's place of residence influenced access to different services, the more upstream forces that shaped land use and transportation were government policy such as zoning bylaws, development regulations and road infrastructure development with the participation of various public and private institutions. This analysis can help policymakers responsible for these decisions regarding locations deficient in specific services in order to improve equitable access. Acting to reduce the transportation and access equity can help move towards a future where people in neighbourhoods of all socioeconomic status, housing prices and ethnocultural composition can enjoy the freedom of accessing the services they need. Such accessibility underlies the principle of the "15-Minute City" with its focus on people being able to reach different services with equal opportunity while achieving the broader goal of reducing automobile dependency and sustainable urban growth (Moreno et al., 2021)The results of this research can help inform policymakers at all government levels by identifying gaps and areas of access inequity that exist in Metro Vancouver. The "15-Minute City" served as both a conceptual

framework to improve a society's well-being and an analytical framework to evaluate and quantify accessibility.

The "15-Minute City" idea and measuring accessibility is not a new concept (Hansen, 1959; Knox, 1980). While many conceptual understandings of healthy neighbourhoods in the past do not directly mention the "15-Minute City", there has been a longstanding consensus that healthy neighbourhoods should have services that support people's daily lives at home, work, and play (Macintyre et al., 2002). Characteristics of healthy neighbourhoods relate to the attributes of a "15-Minute City" such as density, design diversity and walkability, all having environmental, social, and personal benefits (Pozoukidou & Chatziyiannaki, 2021). Increased density is directly related to the increased proximity of goods and services, which can reduce travel time and energy spent on transportation. Density also allowed access to local service and consumption patterns, which promotes more social interactions within a locality (Moreno et al., 2021). Design diversity directly translated to more choices to accommodate different people's demands and needs. This supported cultural diversity and planning inclusion to accommodate different people's perspectives in the same community (Allam et al., 2022; Moreno et al., 2021; Pozoukidou & Chatziyiannaki, 2021). The following section summarizes the various environmental and community health benefits of having access to essential services, illustrating the utility of the "15-Minute City" concept to quantify access equity in Metro Vancouver.

The "15-Minute City" promotes more walkable neighbourhoods while research had shown that areas with more accessible services were correlated with decreasing car ownership and automobile dependency, which was directly associated with environmental benefits such as

reduced traffic-generated air pollution (Bright, 2021). Increased walkability also mediates other environmental exposure related to health such as reduced traffic injuries and noise, which led to a safer environment and community overall (Frank et al., 2019). In general, increased access helps to overcome geographical and psychological barriers to reach goods and services, which lead to a better quality of life and well-being.

Since this study considered six different services, increased access to each of the six services has individual benefits. Access to these six services can increase physical health through increased walking, physical exercise and healthy eating as well as increase mental health through more social interactions with others thus promoting community connection and belongingness (Figure 15) (Frank et al., 2006; Jun & Hur, 2015; Kitchen et al., 2012; Larson et al., 2009; Rugel et al., 2019; Wood et al., 2010). As specific examples, green spaces such as parks have shown a significant positive influence on health such as increased physical activity, reduced blood pressure, obesity and reduced risk of heart diseases, diabetes, pre-term birth and all-cause mortality (Barton, 2009; Lachowycz & Jones, 2013; Nathan et al., 2018b; Twohig-Bennett & Jones, 2018). Behaviour changes such as increased physical activity near greenspaces and other recreational facilities like community centres also promoted social participation, and integration, thus increasing the overall social capital of people (Northridge, 2003). Social network and group membership increase people's sense of belonging and is critical to people's emotional and mental well-being (Barton, 2009; Renalds et al., 2010). Therefore, behaviour changes facilitated by all six essential public infrastructures may help reduce BMI, systematic inflammation and overall stress thus decreasing the risk for chronic illnesses such as hypertension, cardiovascular diseases, and cancer (Frank et al., 2019). The overall benefits of reduced inequity in access

directly translate to more active and healthy neighbourhoods, which have better public health outcomes, community resilience and sustainable development (Allam et al., 2022; Moreno et al., 2021).

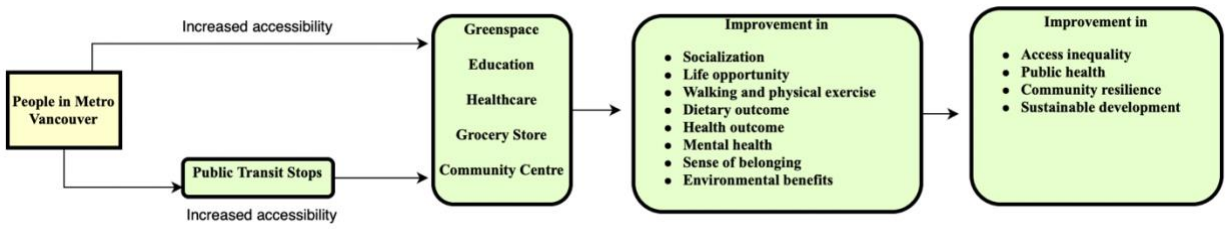

Figure 15 Summary of individual and community benefits from access to essential services

The "15-Minute City" concept also directly corresponds to international and local goals toward sustainable development. The United Nations Sustainable Development Goals 11 called to make cities more inclusive, safe, resilient and sustainable by providing accessible transportation systems, and public spaces and reducing environmental problems (United Nations, 2021), which directly aligned with the philosophy and characteristics of a "15-Minute City". Locally, the equity in access was also advocated by the Greater Vancouver Regional District Livable City Regional Plan, the Metro Vancouver *Metro 2050* plan and the City of Vancouver *Climate Emergency Action Plan* (City of Vancouver, 2020; Metro Vancouver, 2021). For instance, the *Metro 2050* plan Goal 1 focused on developing resilient, healthy, connected and complete communities with a range of services and amenities while Goal 5 focused on supporting sustainable transportation choices such as transit and walking, which all correspond to the concept and objective of this study (Metro Vancouver, 2021). While "sustainable development" may be enacted in different ways in different regions in Canada, the underpinning goal remained the same to develop cities without compromising the needs of future generations including various economic, social, and environmental considerations (World Commission on

Environment and Development, 1987). The “15-Minute City” was directly relevant and applicable to urban planning policies to promote well-being that integrates the goal of achieving service proximity, institutional changes in resource allocation patterns, and considerations of major environmental issues such as climate change (Moreno et al., 2021; Pozoukidou & Chatziyiannaki, 2021).

Furthermore, the COVID -19 pandemic highlighted the need for better resource allocation and access during crisis response and posed a learning opportunity for cities to make changes in the post-pandemic era. For instance, the initial “lock-down” phases of the pandemic in many countries in 2020 demonstrated the importance of essential services such as grocery stores and healthcare facilities to remain open and accessible. However, unequal spatial distribution driven by demographic and social inequalities meant that many people faced barriers to accessing such as not being able to take public transit to reach these essential services. Many countries increased bike lanes and outdoor plazas to promote physical activity and maintain well-being through more active transportation with safe social interactions during the pandemic (Moreno et al., 2021). These were prime examples that demonstrated the importance of access and walkability of a city. Many researchers around the world also viewed the pandemic as a critical opportunity to rethink and reshape urban planning to maintain and add infrastructures that promote access and walkability through the “15-Minute City” (Guzman et al., 2021; Pinto & Akhavan, 2022; Pisano, 2020).

In Canada, Ottawa and Edmonton officially adopted the “15-Minute City” concept in their official plans. The *15-Minute Neighbourhood*s plan in Ottawa outlined the goals to achieve more

housing, retail, commercial and health services, public services, education, greenspace and sustainable mobility for their community while the Edmonton "15-minute districts" will allow more people to easily complete their daily needed within fifteen minutes of their homes (City of Ottawa, 2021; City of Edmonton, 2020). Metro Vancouver's population is expected to grow by one to 3.6 million by 2050 and each regional municipality should consider how to best serve the current capacity and anticipate future population growth (Metro Vancouver, 2018). Therefore, Metro Vancouver could also consider using the "15-Minute City" concept in its regional plans to achieve the goals of complete communities, climate change mitigation, and sustainable development.

4.4 Study Strengths and Contributions

To our knowledge, this was the first study in Canada to quantify access to essential services using the concept of "15-Minute City", which had already been utilized in studies of other international cities (Bright, 2021; Guzman et al., 2017; Wu et al., 2021). Unlike other studies that analyzed access to only one service, this study analyzed access to six essential services such as community centres, grocery stores, healthcare facilities, education facilities, public transit stops and greenspace to realistically represent people's life opportunities. The equitable access to services was also evaluated based on demographic and socioeconomic attributes such as population density, situational deprivation and age structures.

Quantifying the gap in access and equity is an essential step to promoting improvement in resource allocation and optimization for decision-makers. Other cities such as Shanghai which previously adopted the "15-Minute City" concept used their research to inform policymakers to provide full-coverage services, build a pedestrian-friendly street network, and develop affordable

housing (Weng et al., 2019). Similarly, this study can help regional planners and policymakers in Metro Vancouver to better understand the current state of transportation and access inequity to achieve more equitable, resilient, and sustainable development in the imminent future.

The sustainable development of cities is a complex issue that requires the integration of multifaceted perspectives. This study's inclusion of six essential services was an attempt to encompass the various essential services that influence individual and community well-being beyond physical health. The "15-Minute City" was also an innovative and flexible framework that can be integrated into decision-making to measure the equitability of access for current scenarios and future projections in other international regions.

4.5 Limitations

The limitations of this study exist within the original data the choice of destination types, the analytical method, and the general framework. The origin data for this study was based on population-weighted centroid location for each dissemination area, thus did not accurately represent the location of everyone's specific place of residence. For instance, some DAs in Tsawwassen with large areas while only one origin point (the population-weighted centroid) per DA was used to represent where most people live within the DA. This may under or overestimate access for people who did not live close to the population-weighted centroid.

The destination data also posed many limitations. First, the definition of essential services in this study considered only six categories and excluded other services such as entertainment and employment, which some might argue as essential (Deboosere et al., 2019; Guzman et al., 2021). This study also did not consider the quality and negative impacts of these services. For instance,

the quality of food available and opening hours at each grocery store might be different. Consumer purchasing patterns at grocery stores might also be different. Increasing access to grocery stores might mean increased access to unhealthy foods and snacks, which might negatively impact health (Fleischhacker et al., 2011). The suitability of various services was also not considered for this study. For all services, particularly education and healthcare, the result of this study may be an overestimation of access since not everyone who has access to one of these locations will want to access these services, while the services themselves might also be at maximum capacity, for example limited in their ability to take on more students or patients. Similar issues can be seen in public transit where service routing, frequency and time of the day were also not considered. However, these factors significantly impact people's individual choices. Lastly, even if some services exist within fifteen minutes of walking, not all services are equally affordable for everyone or services may be less approachable to some populations due to influences of systemic discrimination.

While data verification was performed for this study, there remain data quality and completion issues. For instance, grocery store data was obtained from OpenStreetMap, which is an open-source database and may contain errors due to store closures or openings. The greenspace data may also be incomplete as many other studies also used normalized difference vegetation index to represent greenspace instead of the physical land use locations of this study (Cusack et al., 2018). While the underlying method used in this study may be replicated in other cities, the data extraction process may not because it relied on various Canadian federal and provincial open data that may not exist in other regions.

Since the “15-Minute City” concept measured access using cumulative opportunity, the destination results assumed all opportunities within the 15-minute buffer zone had the same probability of being reached. For instance, a community centre that is one minute away had the same access as a community centre that was 14 minutes away in this study. Other studies have used the travel time to the closest facility or distance decay-based gravity model to assess access, which can be used to circumvent the limitations of cumulative opportunity methods (Niedzielski, 2021; Robinson et al., 2013).

Moreno et al. (2021) suggested that the concept of “15 minutes” should be flexible and could be tailored to individual cities' needs and characteristics. Different cities had utilized anywhere from 15 to 45 minutes as a buffer radius to measure access. Since the “15-Minute City” first originated in Europe, it might not directly apply to Vancouver since North American cities are “newer” and planned for more automobile-oriented transportation. Currently, there is no research to suggest the optimal walking time for Metro Vancouver based on its road network and zoning plans is 15 minutes. This study also dichotomized access as a “yes or no” question; however, the total number of facilities reached for each DA may also be analyzed to tailor the service capacity to the demand of a neighbourhood (Wu et al., 2021).

These location-based measures also ignored individual components of travel (Cerdá, 2009). The travel speed was set to 3.6 or 4.8 KM/H, which did not individually represent everyone in the population and the R5R routing calculations also did not consider the waiting time during intersection crossing or road elevation, factors impacting travel duration.

This study also used situational deprivation from the Canadian Index of Multiple Deprivation (2016) as an alternative representation of socioeconomic status. While the index considered the effect of the Indigenous populations, education, living condition, single-parent families and income, many other factors may also impact socioeconomic status such as immigration status and ethnocultural composition. The situational deprivation dimension also does not include the effect of race as an indicator of situational deprivation. Race was analyzed in a separate dimension within the CIMD as "ethnocultural composition", which was not included in this study. However, future studies may include the analysis of ethnocultural composition from the CIMD. Overall, area-based socioeconomic composite indicators are still more favourable than using a single measure of socioeconomic status such as income. Composite indices have also been favourable choices for analyzing community-level equity issues such as healthcare (Relova et al., 2022).

Overall, this study advocated for more equitable access thus implying increased land-use mix and density. However, empirical evidence suggests that high-density development can both positively and negatively impact satisfaction (Bramley et al., 2009; Cao, 2016). Although compact cities are more convenient and have better access to goods and services, the impact of high density, small space, and insufficient greenspace may also compromise the quality of life (Aalbers & Eckerberg, 2011; Westerink et al., 2013). Therefore, the trade-off between high access and density needs to be taken with care.

4.6 Future Considerations

The implementation of the "15-Minute City" concept has its challenges. For example, the *Plan Melbourne 2017-2050* revealed that their "15-Minute City" strategy was strong on COVID

safety planning and weaker on increasing proximity to employment, healthcare and fresh food (Pozoukidou & Chatziyiannaki, 2021). This demonstrated the implementation barriers of the "15-Minute City" concept such as inclusion, health, safety and physical planning and community building processes. *Paris en Commun*, which was the global initiator of the "15-Minute City" also faced challenges such as creating more access in affluent regions of central Paris and leading to more social segregation in rural areas (Pozoukidou & Chatziyiannaki, 2021). Other challenges were seen in Singapore where rigid zoning posed significant obstacles to building more infrastructure to increase access and fulfill their 20-Minute Towns and a 45-Minute City goal (Manifesty et al., 2022). Therefore, Metro Vancouver should also anticipate its challenges when increasing access in general.

Some unique challenges of Metro Vancouver may include the promotion of economic prosperity, affordable housing, climate change mitigation and reconciliation with Indigenous communities while also increasing equity in access and community health (Metro Vancouver, 2021). Additionally, Metro Vancouver municipalities are also not strictly defined by boundaries; therefore, considerations between city connectivity and access are also important. While increasing access, different services' safety and inclusion should also be ensured so people utilizing the services are interacting with others in the community to truly fulfill the goals of connected and complete communities in Metro Vancouver.

Extensions of this project may include access to each sub-category of essential services or adding an evaluation weighting component to each service. Future research may also modify the research methodology to address each of the limitations mentioned above such as evaluating

access from the perspective of service quality, inclusion, and affordability. Different modes of transportation can also be included in future studies such as cycling and public transit. Another major pillar of the "15-Minute City" not included in this study is digitization, which considers the use of technology to change consumer and access patterns (Moreno et al., 2021). Therefore, future research may evaluate the impact of online food delivery services on grocery store access or social media's influence on community engagement and socialization patterns. Negative impacts of certain services can also be considered such as fast-food restaurants or liquor stores. Overall, the framework of "15-Minute City" and the method used in this study may be replicated in other Canadian and international cities to analyze the equity of access to services in their respective communities.

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Appendices

Appendix A Regional and Municipal Plans: Objectives and Goals

Specific objectives and goals from regional and municipal plans were summarized in this section. This policy scan was done to determine critical services mentioned in major urban development plans as the rationale for supporting the choices of essentials services selected at the end of the study, which was greenspace, grocery stores, community centres, public transit stop, education facilities and healthcare centres. Using essential services mentioned consistently across different levels of government can better inform decision-making regarding making these services more available in the future.

Table A.11 Specific objectives and goals within regional and municipal plans that correspond to the "15-Minute City" rationale

Region	Plan	Objective and Goals
Metro Vancouver	*Metro Vancouver 2040 Shaping Our Future* (2020)	Goal 4 Develop Complete Communities • Strategy 4.2 Develop health and complete communities with access to a range of services and amenities Goal 5 Support Sustainable Transportation Choices • Strategy 5.1 Coordinate land use and transportation to encourage transit, multi-occupancy vehicles, cycling and walking

		• Strategy 5.2 Coordinate land use and transportation to support the safe and efficient movement of vehicles for passengers, goods and services
City of Burnaby	*Burnaby Social Sustainability Strategy* (2011)	• Strategic Priority 1 Meeting Basic Needs and Healthy Living • Strategic Priority 3 Strengths to build on civic and community engagement (parks and recreation) • Strategic Priority 5 Enhancing Neighbourhoods
City of North Vancouver	*Official Community Plan* (2014)	Goal 2. Transportation, Mobility and Access • Goal 2.1 Prioritize walking, cycling, transit and good movement over single-occupancy vehicles • Goal 2.2 Integrate land use and transportation planning to reduce the need for car travel • Goal 2.3 Support a safe accessible resilient, affordable transportation system Goal 3. Community Well-being • Goal 3.1 Enhance well-being and quality of life for all community members • Goal 3.4 Increase access to nutritious, safe, healthy, local food and opportunities for residents to grow their wood Goal 5. Parks, Recreation and Open Space

		• Goal 5.2 Support, enhance, maintain recreation as a vital aspect of a healthy community • Goal 5.3 Provide a variety of public spaces for community engagement and stewardship
City of Richmond	*Official Community Plan* (2012)	Goal 3. Connected Neighbourhoods with Special Places • Objective 3.1.2 Promote diversity of land uses and densities that support a wide range of residential, employment, and daily shopping, personal services and enhanced transit services • Objective 3.2.4 Recognize the importance of schools in neighbourhoods • (e.g., education, daycare, recreation, health, literacy and • community life). • Objective 3.2.4 Ensure that the City's neighbourhoods accommodate a range of uses with convenient access to jobs, services, and recreation. • Objective 3.2.5 Improve walking, rolling, bicycling linkages within neighbourhoods to create safer, more convenient, and attractive routes to multiple destinations a short distance from home

City of Surrey	*Official Community Plan* (2013)	Theme B Centres, Corridors, and Neighbourhoods • Objective 4 Build complete, walkable, and green neighbourhoods • Objective 3 Transit Corridors Theme F Society and culture • Objective 4 Provide healthy and accessible active living opportunities • Objective 5 Improve access to healthy, local food • Objective 6 Ensure accessible and inclusive civic facilities, programs and community services
City of Vancouver	*Healthy City Strategy* (2016)	• Goal 1 Vancouver's children have the best chance of enjoying a healthy childhood • Goal 3 Vancouver has a healthy, just and sustainable food system • Goal 4 Vancouver has equitable access to high-quality social, community and health services • Goal 8 Vancouverites are engaged in active living and have incomparable access to nature • Goal 9 Vancouverites have equitable access to lifelong learning and development opportunities • Goal 11 Vancouverites enjoy safe, active and accessible ways of getting around the city

City of West Vancouver	*Official Community Plan* (2018)	B. Local Economy • Goal 2.3 Strengthening commercial centres and nodes C. Transportation and Infrastructure • Goal 2.4 Encourage walking and cycling E. Social Well-being • Goal 2.8 Enhancing public facilities and spaces; promoting engaged community • 2.9 Enabling an active community and enhancing community health

Appendix B Data Sources

This section showed the website links to all the data obtained for this study.

Table B.12 Sources and website links of data

Data	Source
Population weighted Centroid, population size, DA area	https://www12.statcan.gc.ca/census-recensement/2011/geo/ref/att-eng.cfm
Age	https://open.canada.ca/data/en/dataset/8d570b5b-b36f-4a6a-be32-f876ed5e03f0
Hospitals	https://catalogue.data.gov.bc.ca/dataset/hospitals-in-bc
Urgent care centres	https://catalogue.data.gov.bc.ca/dataset/emergency-rooms-in-bc

	https://catalogue.data.gov.bc.ca/dataset/urgent-and-primary-care-centres https://catalogue.data.gov.bc.ca/dataset/urgent-and-primary-care-centres
GP/walk-in clinics	https://catalogue.data.gov.bc.ca/dataset/walk-in-clinics-in-bc
Pharmacies	https://catalogue.data.gov.bc.ca/dataset/after-hours-pharmacies-in-bc
Mental Health and Substance Use Health Services	https://catalogue.data.gov.bc.ca/dataset/mental-health-and-substance-use-health-services
Grocery Stores	https://wiki.openstreetmap.org/wiki/Tag:shop=grocery https://wiki.openstreetmap.org/wiki/Tag:shop%3Dgreengrocer https://wiki.openstreetmap.org/wiki/Tag:shop%3Dsupermarket
Greenspace	https://catalogue.data.gov.bc.ca/dataset/local-and-regional-greenspaces
Daycare	https://catalogue.data.gov.bc.ca/dataset/child-care-map-data
Schools	https://abacus.library.ubc.ca/dataset.xhtml?persistentId=hdl:11272.1/AB2/YEIXMO https://catalogue.data.gov.bc.ca/dataset/school-enrollment
Community Centres	Municipality Website (i.e. https://vancouver.ca/parks-recreation-culture/community-and-cultural-centres.aspx)

Public Transit Stops	https://abacus.library.ubc.ca/file.xhtml?persistentId=hdl:11272.1/AB2/LMLPT1/CAFWGZ
OpenStreetMap Road network	https://www.geofabrik.de/data/download.html
Canadian Index of Multiple Deprivation	https://open.canada.ca/data/en/dataset/5c670585-97ed-4e6a-a607-30fab940ff88
Metro Vancouver DA Boundary Shapefiles	https://www12.statcan.gc.ca/census-recensement/2011/geo/bound-limit/bound-limit-2016-eng.cfm

Appendix C DMTI Food Store Query Keys

Various open data sources were available to obtain the locations of food stores in Metro Vancouver. One of such method was using the DMTI Enhanced Points of Interest (EPOI) V2013.3. The queried keys for data collection were listed in Table C.1. Upon obtaining the dataset from the DMTI EPOI data, it became apparent that the DMTI data included fast food stores, convenience stores and wholesale food retails that were not directly marketed to consumers. Since the study objective was to look at accessibility to grocery stores, this study preferred having locations of full-service grocery stores only that often had healthier food options compared to convenient stores. However, locations of unwanted food stores were difficult to filter out since they were embedded in the queried keys unless manual filtration was used. Furthermore, the DMTI data dated back to 2013, which was closed to a decade out of date to the current time. Therefore, based on the lack of differentiation between convenience stores and wholesale food retailers and up-to-date data, the DMTI EPOI was not used for this study. Instead, OSM grocery store data was used.

Table C.13 Queries keys for food stores in the DMTI Enhanced Points of Interest V2013.3

Keys	Description
SIC 5149	Groceries and Related Products
SIC 5141	Groceries General Line
SIC 5411	Groceries stores
SIC 5421	Meat and Fish Markets
SIC 5431	Fruits and Vegetable Markets
SIC 5499	Miscellaneous Food Stores

NAISC 42241	General Line Grocery Wholesaler
NAISC 42249	Other Grocery and Related products wholesale
NAISC 44511	Supermarkets and Other Grocery (except convenience stores)

Appendix D R5R Analysis

D.1 Travel Duration Procedure Summary

The travel duration calculation procedure using R5R can be summarized as below:

1. Download Java Development Kit 11 and increase Java memory by 2GB
2. Build routable transport network using setup_r5() and BC Open Street Map data obtained from Geofabrik
3. Calculate travel time matrices
    a. Import origin points
    b. Import destination points
    c. Set max trip duration to 15 minutes
    d. Set transportation mode (walking)
    e. Set travel speed (3.6 or 4.8 KM/H)
4. Export travel duration results (12 matrices) and remove duplications

D.2 Data Production R Code

```
install.packages('r5r')

devtools::install_github("ipeaGIT/r5r", subdir = "r-package")

options(java.parameters = "-Xmx2G")


library(r5r)

library(tidyverse)

library(devtools)

library(sf)

library(data.table)
```

```
library(ggplot2)
library(akima)
library(dplyr)

#Set "path" to where the road network exists (OSM data in this case)
#Set up road network in r5r
r5r_core <- setup_r5(data_path = path, verbose = FALSE)

#Import origin and destination data with (id, lat,long)
#Calculate Walking Time
#Example: Access to grocery store by 3.6 KM/H
grocwalk3.6<- travel_time_matrix(r5r_core = r5r_core,
                                 origins = #origindata,
                                 destinations = #grocerystoredata,
                                 mode = "WALK",
                                 max_trip_duration = 15,
                                 walk_speed = 3.6,
                                 verbose = FALSE)

#Repeat the same steps for greenspace, community centre, healthcare, education, public transit
#Repeat the same process for the faster walking speed 4.8 Kof M/H
#12 total matrices created in the end
```

```
#Result processing (Repeat for each service category and walking speed)

##Frequency count of a grocery store within 15 minutes of walking for each DA

grocwalk3.6_freq<- count(grocwalk3.6,"fromId")


#Adding binary counts

walk_result$grocwalk3.6 <- as.numeric(walk_result$grocw3.6>0)
```

Appendix F Additional Map

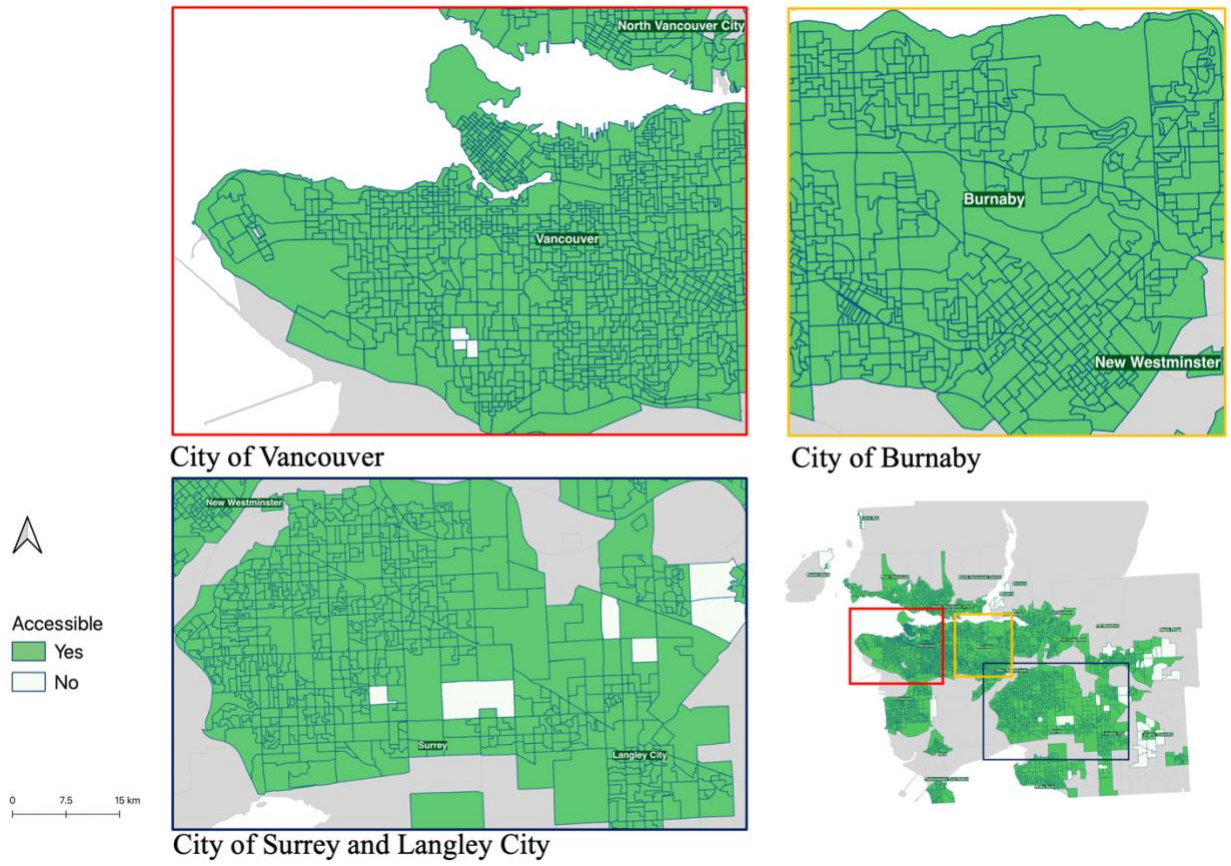

Figure F.1 Greenspace reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

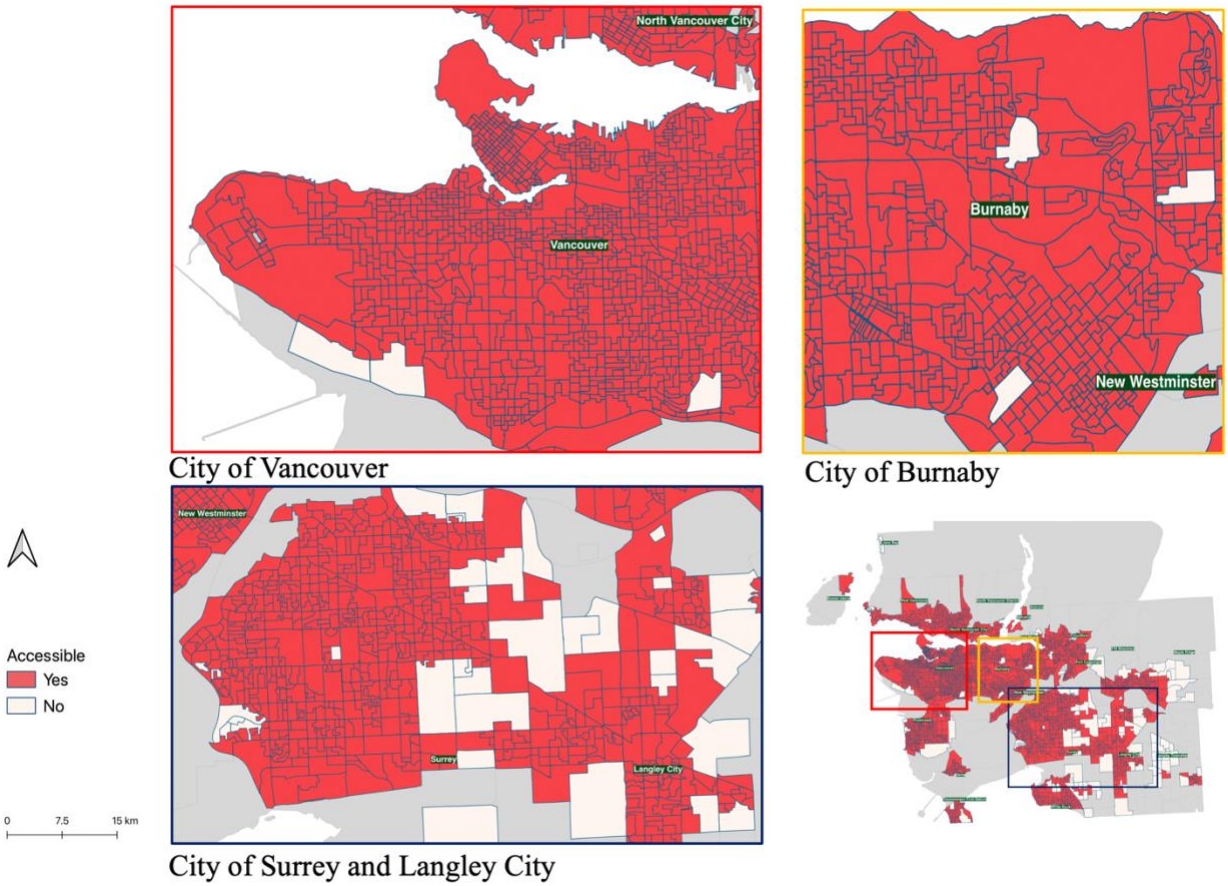

Figure F.2 Public Transit Stops reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

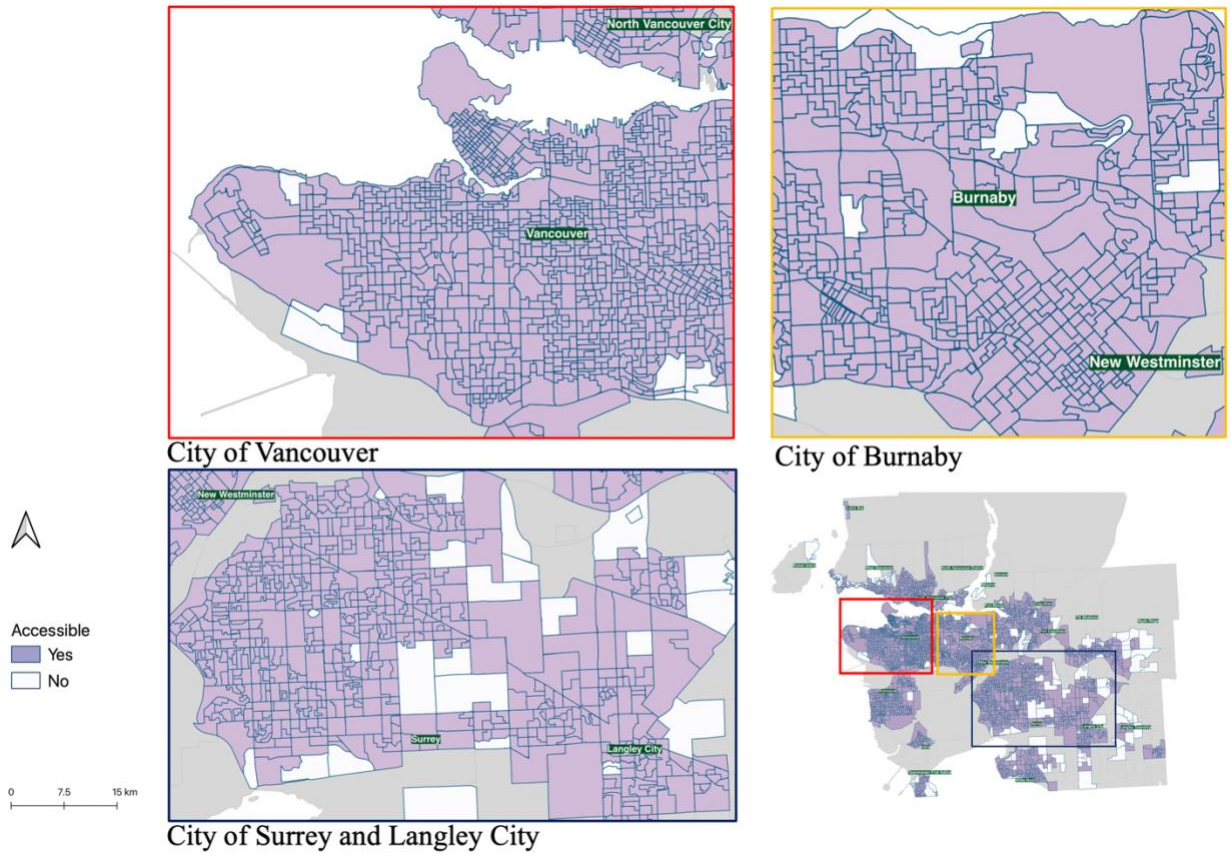

Figure F.3 Education Centres reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

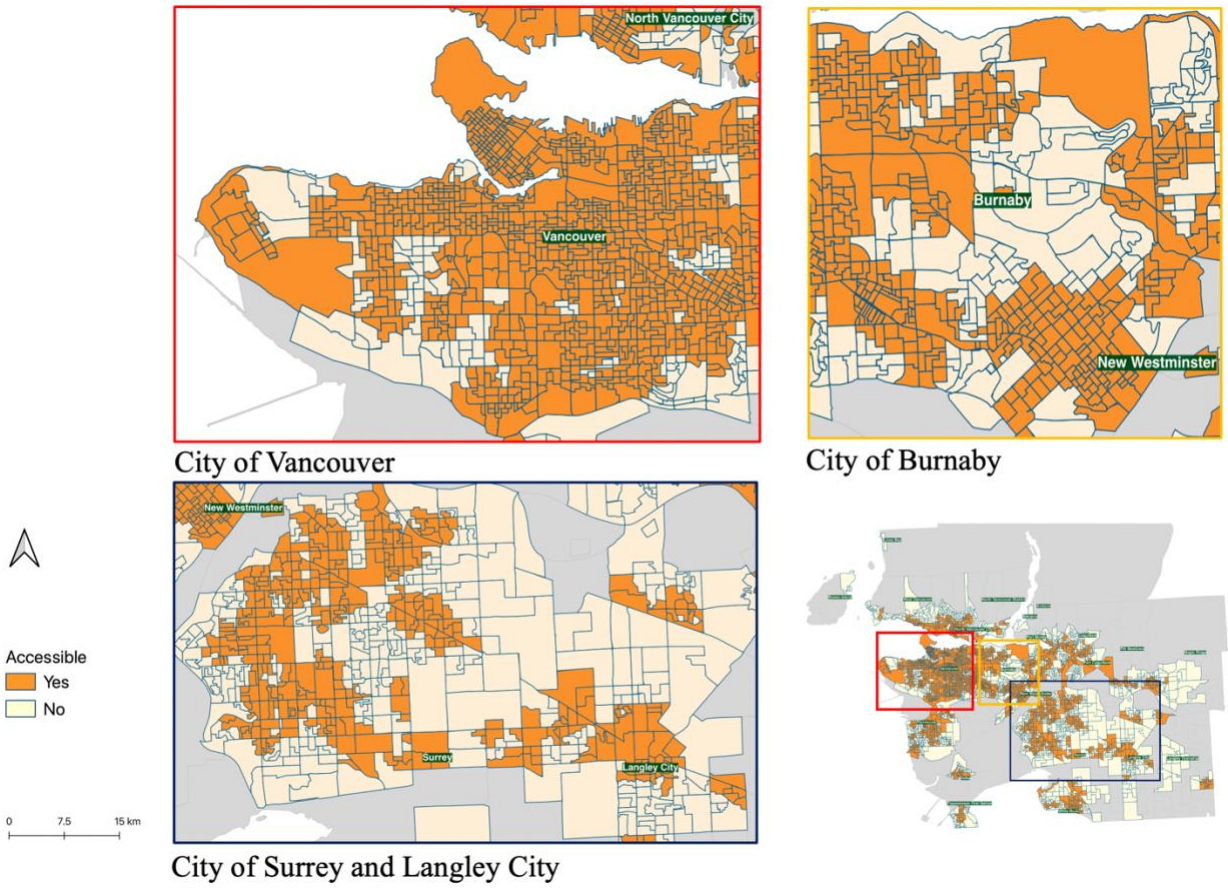

Figure F.4 Healthcare Centres reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

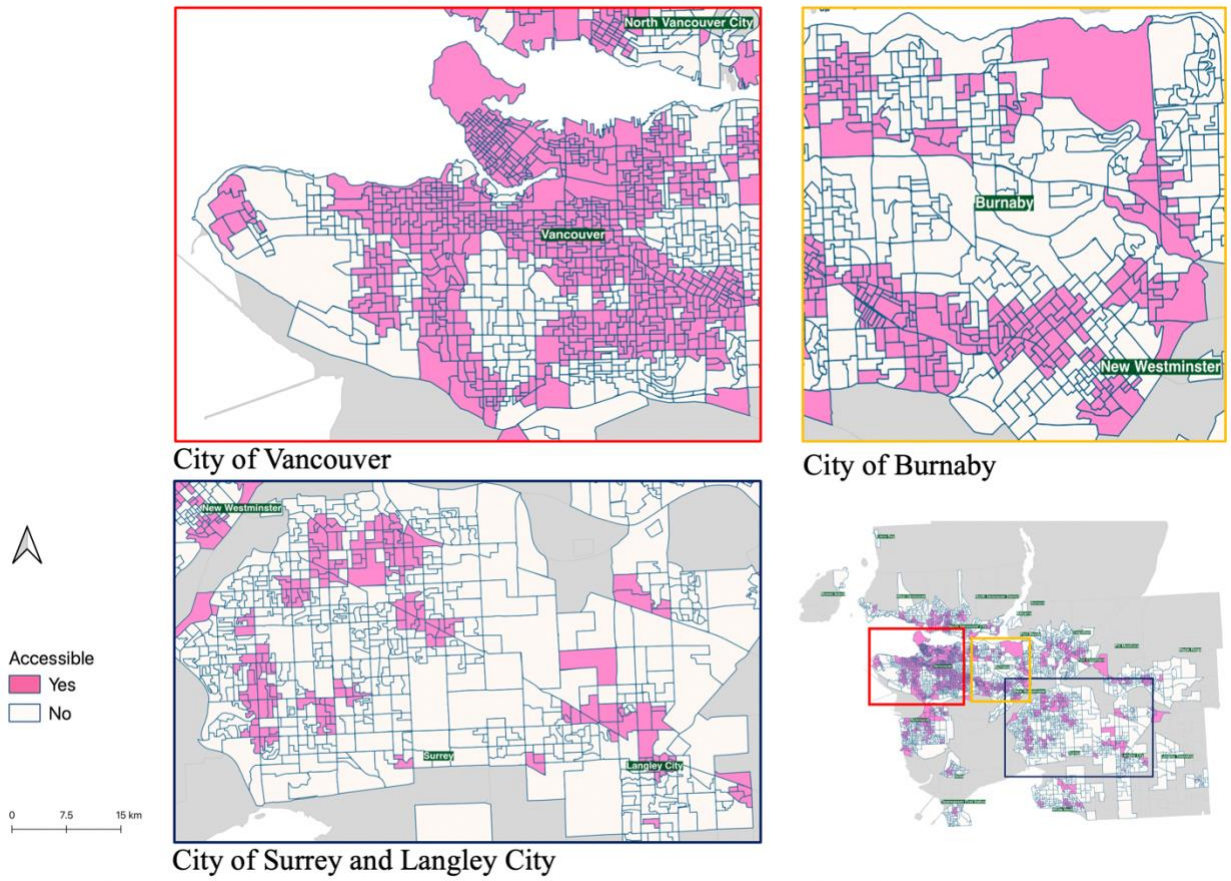

Figure F.5 Grocery Stores reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

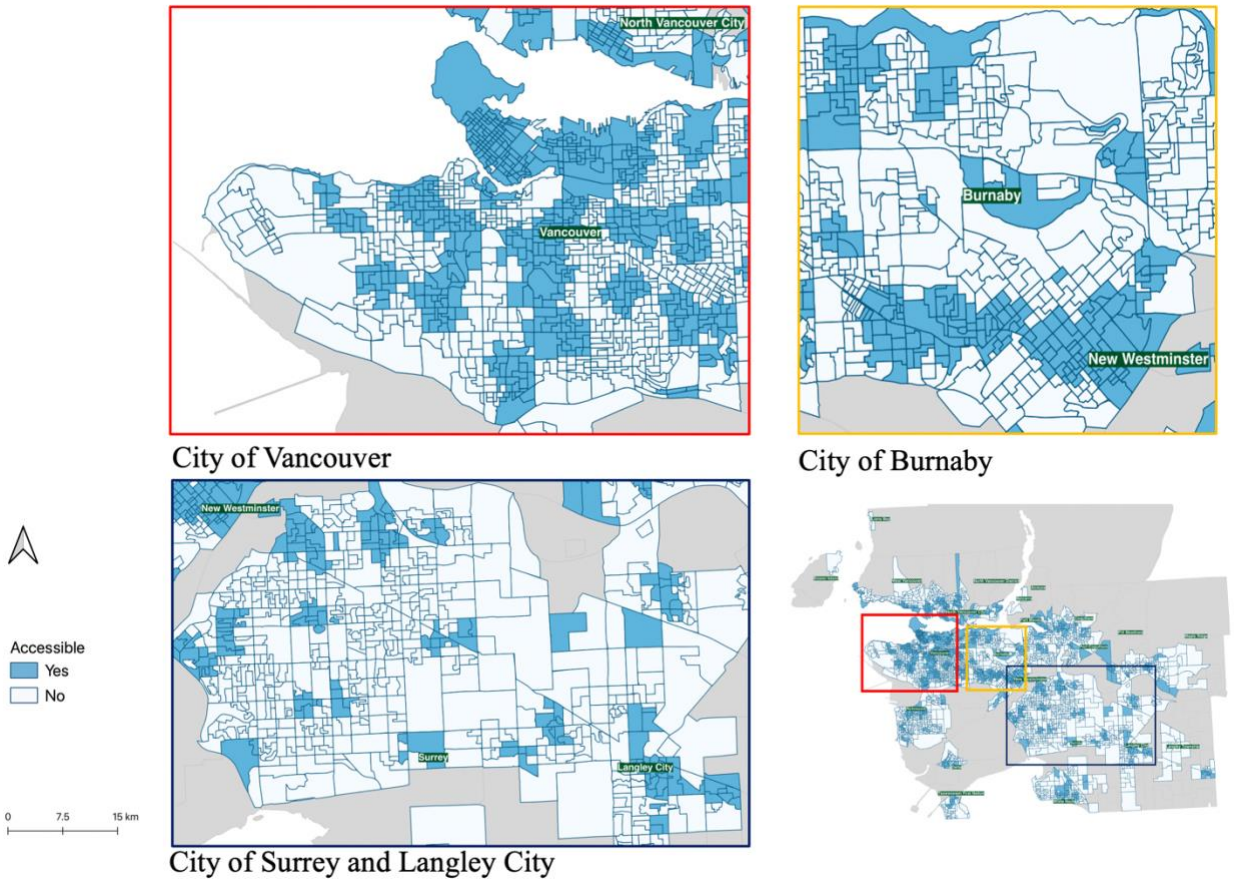

Figure F.6 Community Centres reached within 15 minutes of walking (3.6 KM/H) in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

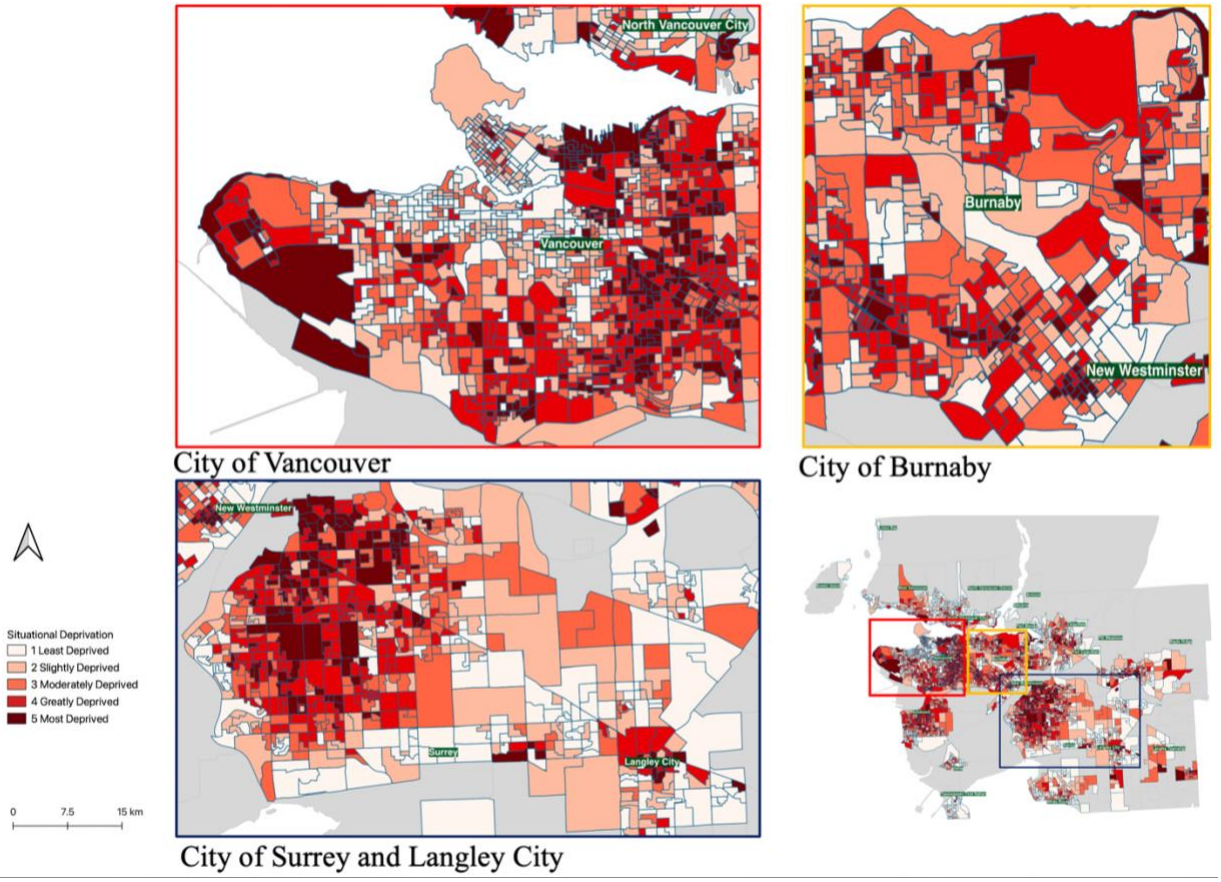

Figure F.7 Distribution of situational deprivation in Metro Vancouver based on the Canadian Index of Multiple Deprivation (2016) for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs

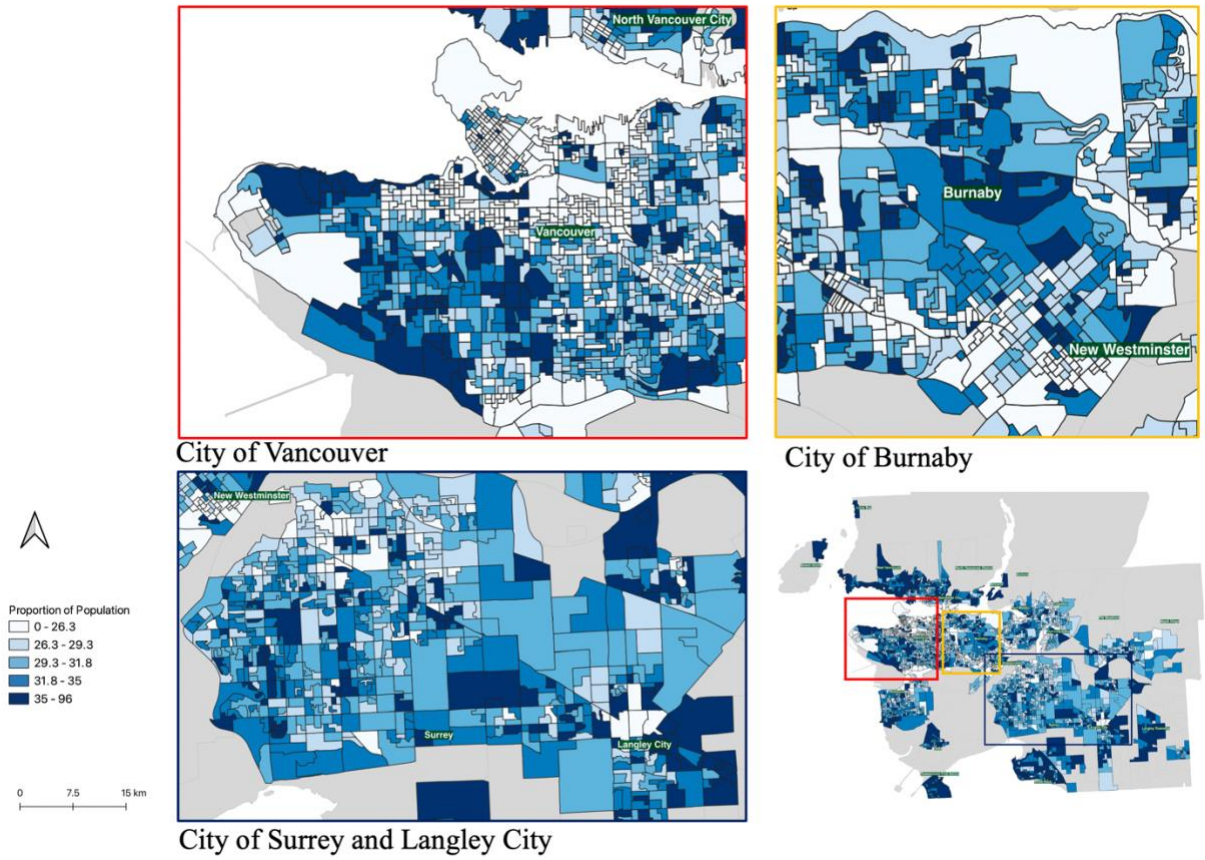

Figure F.8 Distribution of the proportion of the population who are aged 0-14 or 65+ in Metro Vancouver for the City of Vancouver, Burnaby, Surrey and Langley. City of Vancouver, Burnaby and Surrey were the three municipalities with the largest number of DAs