Geographic Variation in Cardiovascular Disease Mortality: A Study of Linking Risk Factors and Built Environment at a Local Health Unit in Canada

Lei Wang, Chris I. Ardern, and Dongmei Chen

Abstract Cardiovascular disease (CVD) is one of the leading causes of death in Canada. CVD risk factors and outcome data are used to determine trends of disease risk to inform public health program planning for prevention and control of disease and risk reduction or elimination. Recent efforts to map CVD and its associated risk factors at the health region level have provided further insights into variation in determinants across populations. In this chapter, geographic information system (GIS) and spatial analysis were utilized to enhance CVD surveillance to identify the patterns and relationships between CVD mortality and its potential risk factors. Ordinary Least Squares (OLS) regression and Geographically Weighted Regression (GWR) approaches were used to explore geographical variation in the rate of CVD mortality. After consideration of potential environmental, epidemiological, demographic, and socioeconomic factors, spatial statistics analysis revealed geospatial clustering for CVD mortality and the "hot spots" or "cold spots." Within a mixed rural-suburban setting in Ontario, Canada, there was an evidence of significant built environmental factors and immigrant time associated with the rate of CVD mortality. Moreover, this pilot work suggests that the integration of geospatial information with routinely collected surveillance data appears feasible within the structure and resources of local public health units as a means to assist in the identification of regional variation in the burden of CVD.

L. Wang
Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, Beijing, China

Department of Geography and Planning, Queen's University, Kingston, ON, Canada

C. I. Ardern
School of Kinesiology and Health Science, York University, Toronto, ON, Canada

D. Chen (✉)
Department of Geography and Planning, Queen's University, Kingston, ON, Canada
e-mail: chendm@queensu.ca

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1 Background

Cardiovascular disease (CVD) is one of the leading causes of death in Canada, representing 22.7% of all deaths in 2009 (Public Health Agency of Canada 2016). Data from Statistics Canada show that the mean 10-year risk of CVD events in the population aged 20–79 was 8.9% during 2007–2011 (Statistics Canada 2017), and data from the Canadian Community Health Survey (CCHS) suggest that four in five of the population between the ages of 20 and 59 years have at least one modifiable risk factor (Heart and Stroke Foundation of Canada 2016). Many modifiable and non-modifiable risk factors can contribute to the high prevalence of CVD, and it is also well known that the burden of CVD is unequally distributed in outcomes, determinants and risk factors across subgroups of the population (Tanuseputro et al. 2003; O'Donnell and Elosua 2008). In broader terms, there is also marked geographic difference in CVD indicators, determinants, and risk factors, as well as mortality (Chow et al. 2005; Filate et al. 2003; Hall and Tu 2003; Lee et al. 2009; Leal and Chaix 2011). Recent efforts to map CVD and its associated risk factors (e.g., smoking, obesity, inactivity, low income, hypertension, and diabetes) at the health region level have provided further insight into variation in determinants across populations (Tu et al. 2006; CDC 2017).

Early studies have shown that more than 70% of global CVD is attributable to modifiable risk factors such as unhealthy lifestyles, policy factors, as well as features of the social and built environment (Ezzati et al. 2003; Sallis et al. 2012; Malambo et al. 2016). The "built environment" comprises urban design, land use, and the transportation system, and encompasses patterns of human activity within the physical environment (Handy et al. 2002; Sallis et al. 2012). Although the importance of individual-level determinants (such as age, gender, income, education) on physical activity and obesity is well described, the influence of environmental determinants of health relating to "place" (i.e., the social experience of the environment) and "space" (i.e., the physical environment) is infrequently integrated into chronic disease surveillance and may offer considerable insight into risk factor clustering of cardiovascular morbidity and mortality through modifiable risk factors such as physical inactivity and obesity (Heath et al. 2006; McCormack et al. 2004; Sallis et al. 2012). The link between the built environment and health has been the focus of an increasing number of studies in recent years (Chum and O'Campo 2015; Malambo et al. 2016). However, the importance of the neighborhood built environment across a range of health outcomes has not been fully explored, and there is currently no consensus as to the relative impact of the built environment and collective community factors on cardiovascular morbidity and mortality (Malambo et al. 2016).

In Canada, CVD risk factor surveillance data sources, including vital statistics, hospitalization records, census and health surveys, are commonly used to inform public health program planning for prevention and control of CVD and risk reduction or elimination. Although existing sources of data for chronic disease surveillance include information that can be geocoded to the municipality, city, or community, application of such frameworks to enhance routine surveillance of CVD at the local level has rarely been implemented (Holowaty et al. 2010; Odoi et al. 2005; Caley 2004). More discrete geographical units with other community-level health determinants should be considered as vital elements to future surveillance strategies, as this would allow for informed public health decision-making and targeted program planning for the areas of highest need. This approach may be particularly informative for the coordination, allocation, and delivery of public health services and interventions within the context of a rapidly growing, geographically and demographically distinct areas. The fast pattern of growth in both residential and employment areas suggests a need to monitor cardiovascular disease risk, morbidity, and mortality risk factors within the public health unit and to explore their relation with the built environment. Furthermore, monitoring various risk factors could provide opportunities to identify areas or regions where disease risk factors are clustered together which could then be investigated to help inform future policy-makers and urban planners how the neighborhood could be altered in future development plans to decrease the overall number of cases. Therefore, it is important to document the methodology and process by which geospatial analysis may be implemented, and to assess whether or not this strategy would help identify clusters of disease determinants that will allow for targeted public health programs and policies to those most at risk.

Application of geographic information system (GIS) and spatial statistics to assess built environment and improve public health, epidemiology, and health planning has been growing in the last two decades (Pickle 2002; Yiannakoulias et al. 2009; Cerin et al. 2009; Thornton et al. 2011). However, there has yet to be a surveillance system that monitors disease outcomes, associated risk factors, and social determinants, using a spatial framework on an ongoing basis to detect temporal and spatial trends. When taken together, the persistence of regional differences in CVD outcomes and risk factors in Canada emphasizes the need for effective surveillance of chronic disease risk factors in addition to patterns of healthcare utilization. The purpose of this chapter is to, therefore, evaluate the use of spatial approaches to analyze the spatial variation of CVD mortality at the local public health unit level in Ontario, considering the potential impact of the "built" physical environment. To date, there is no existing single surveillance system in place that monitors all disease outcomes, associated risk factors and social determinants for CVD.

This pilot study, funded by the Public Health Agency of Canada, brought together urban planners, public health officials, epidemiologists, and policy-makers from The Regional Municipality of York, with academic researchers to explore the relationship between CVD risk factors and built environment. To achieve the project objectives, a combination of respondent-level risk factor data from the Canadian Community Health Survey (CCHS), determinant data from the Census of Canada, and CVD morbidity and mortality outcome data from intelliHEALTH ONTARIO in concert with spatial data was used.

2 Methods

2.1 Study Area

The study area was the York region of southern Ontario, Canada (Fig. 1). It belongs to the Greater Toronto Area and is about 1762.17 km^2 in area, consists of 155 census tracts (CTs), and had a population of 1,032,524 in the 2011 Census based on Statistics Canada (2016). The population in the 155 CTs ranged from 1970 to 18,959 persons and the population density ranged from 22 to 8580 persons per square kilometer in 2011. During the period of 1996–2001, York Region was one of the fastest-growing census divisions in Canada (Bryan et al. 2006).

Risk factor surveillance in York Region was limited to individual-level survey data provided by routinely collected sources such as the Canadian Community Health Survey and Rapid Risk Factor Surveillance System. In light of the consistent finding of regional (e.g., provincial and rural/urban) and demographic (e.g., ethnicity and time-in-country) variation in traditional CVD risk factors (Tremblay et al. 2005, 2006), critical insight into contributors to inequities in cardiovascular morbidity and mortality may be provided by the integration of geospatial information with

Fig. 1 The location of the study area

existing risk factors and health event data. However, to date, only limited attempts have been directed to multi-level modeling and surveillance to assess the joint effects. The coordination and integration of multiple sources and levels of data will provide a resource on which to build a system that can integrate individual and community-level determinants and risk factors in an effort to enhance existing primary prevention strategies.

2.2 Data

Multiple independent variables were captured from the CCHS dataset, census, and GIS data to account for environmental, epidemiological, demographic, and socioeconomic characteristics and risk factor for CVD morbidity and mortality. The values of poorer states of health of each variable (i.e., obesity, hypertension, diabetes, heavy drinking, heavy smoking, and sedentary lifestyle) were included within the models for spatial analysis.

2.3 Canadian Community Health Survey (CCHS)

CCHS is a nationally representative population-based cross-sectional survey conducted by Statistics Canada. The CCHS collects information on the health status, healthcare use, and health determinants of Canadians aged 12 years or older living in private households. The target population of the CCHS included household residents in all provinces and territories. Residents of indigenous lands, institutions, some remote areas, and military bases were not included. While there was one randomly selected respondent per household, planned over-sampling of youths resulted in a second member of some households being interviewed. Participants provided their demographic, socioeconomic, behavioral, and health-related information. Cycle 3.1 (2005) was used for use in this study to match the available mortality and morbidity data. For Cycle 3.1, interviews were conducted between January and December 2005. The response rate was 79%, yielding a national sample of 132,947 respondents, with a total of 1681 respondents in York Region. Three sampling frames were used to select the sample of households: 49% of the sample of households came from an area frame; 50% from a list frame of telephone numbers; and the remaining 1% from a Random Digit Dialing (RDD) sampling frame. The distribution of the samples in the study area is shown in Fig. 2.

A number of CVD risk factors were identified after conducting a literature review of cardiovascular disease risk factors. Table 1 lists these data and risk factors selected in this study and their description and rationales.

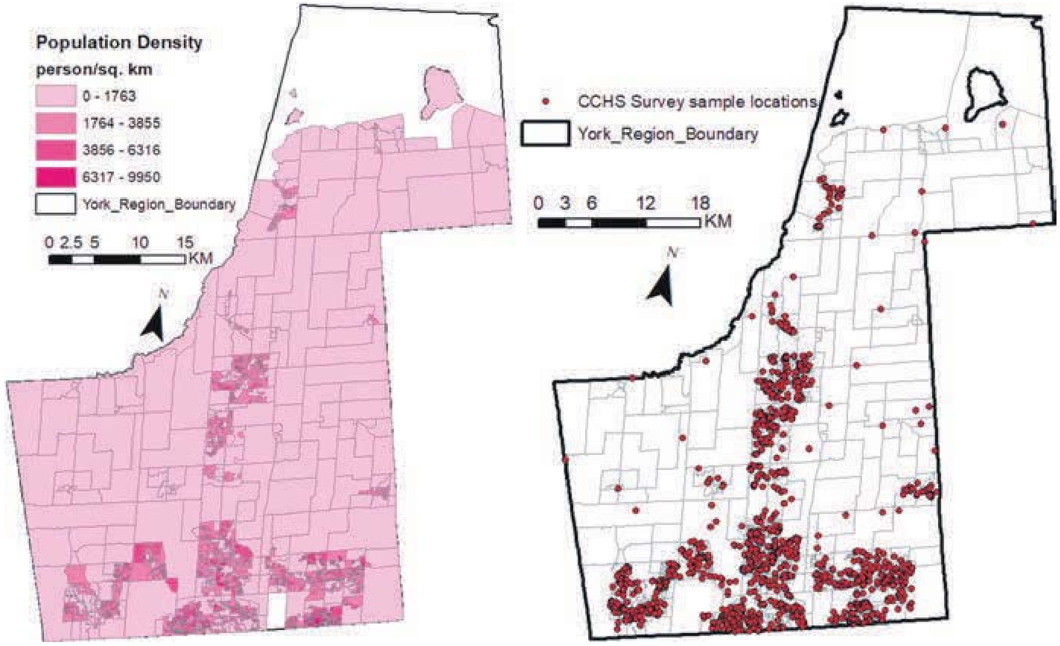

Fig. 2 The population density (left) and location of CCHS survey samples (right) geocoded based on their six-digit postal codes within the York Region

2.4 Postal Data

The postal data used in this study was the unique enhanced postal (UEP) codes data produced by DMTI Spatial Inc. (https://www.dmtispatial.com/). The data contains postal code points positioned to the most representative address and allows for a 1:1 relationship wherein one postal code matches to one postal code location. Each postal code is attributed by its spatial coordinates, census population, and other determinant data. In UEP, postal code regions are determined based on their corresponding dissemination area (DA) regions. Where postal codes serve more than one DA (such as in both rural and urban areas of Canada), postal codes are assigned to DAs based on an unbiased population weighted random allocation method. In cases where valid postal codes cannot be used to assign the full range of geographic identifiers, the first two or three characters in the postal code are used to assign partial geography.

A six-digit postal code residential information was captured for each respondent from the share file of the CCHS database. Geocoding was subsequently applied in ArcGIS to retrieve the associated geographic coordinates of each CCHS respondent using UEP codes for the purpose of visualization of patterns and further analysis. Since the analysis unit of this study is census tracts (CT), a spatial join was applied in ArcGIS to assign CCHS respondent into census tract units to get the count number of CCHS respondent in each CT. CVD risk factor rates (obesity, hypertension, diabetes, heavy drinking, heavy smoking, sedentary lifestyle, low income, low

Table 1 CVD data and its risk factors from CCHS Cycle 3.1

Category and indicator	Quality of data (has indicator been used in other research?)	Description of data	Is data available for use?	Selected for analysis?
Demographics				
Age	Shigematsu et al. (2009)	Age accurate to single year	Yes	Yes
Sex	Bennett et al. (2007)	Female/male	Yes	Yes
Education	Berrigan and Troiano (2002)	Based on respondent's highest level of educational attainment	Yes	Yes
Income	Gordon-Larsen et al. (2006)	Based on respondent's income level	Yes	Yes
Housing	Agreement by senior members	Household size (number of residents)	Yes	Yes
Country of birth	Berrigan and Troiano (2002)	Considered white or visible minority	Yes	Yes
Recent immigrant status	Agreement by senior members	Average length of time in Canada since immigration	Yes	No
Health indicators (risk factors/ behaviors)				
Leisure time physical activity index	Hoehner et al. (2005)	Based on extensive list of activities with questions relating to frequency and duration	Yes	Yes
Smoking	Ross (2000)	Smoking classification for frequency and type	Yes	Yes
High blood pressure	Li et al. (2009)	Self-reported physician-diagnosed high blood pressure	Yes	Yes
BMI	Evenson et al. (2007)	Based on self-reported height and weight measurements	Yes	Yes
Fruit and vegetable consumption	Ball et al. (2009)	Daily consumption of fruits and vegetables	Yes	Yes
Diabetes	Agreement by senior members	Based on self-reported response to physician-diagnosed diabetes	Yes	Yes
Access to physicians	Agreement by senior members	Access to a medical physician	Yes	Yes

consumption of fruit and vegetable, and inaccessible to physicians) were calculated by the frequency of each risk factor by the count number of population in each CT. Average age, percentage of males, percentage of rent dwelling, and average length of time in Canada since immigration were also calculated.

2.5 Census

Socioeconomic and demographic data were derived from Census of Canada profiles. The census is carried out every 5 years and is a reliable source of social and demographic information for the population of Canada. Socioeconomic information was collected from 20% of the households, surpassing the sample size of any available population-based survey. In urbanized areas of Canada, Statistics Canada classifies Canadian geography using the Statistical Area Classification (SAC) for data dissemination purposes and breaks down areas of Canada into census metropolitan areas (CMAs), census agglomeration areas (CAs), CTs and DAs. CTs are small, relatively stable geographic areas with a population of ~2500 to 8000, whereas DAs are the smallest geographic unit at which Statistics Canada reports complete census information, and typically consist of between 400 and 700 people. Considering the distribution of CCHS cases, after comparing the case maps at CT and DA levels, CT was selected as the unit of analysis for characterization of spatial autocorrelation and regression analysis, as many DAs did not have a sufficient number of cases (Table 2).

Table 2 Risk factors obtained from 2006 census data

Category and indicator	Quality of data (has indicator been used in other research?)	Description of data	Is data available for use?	Selected for analysis?
Demographics				
Total number of low education (no certificate, diploma or, degree)	Berrigan and Troiano (2002)	Total number of population with no certificate, diploma, or degree in CT	Yes	Yes
Average income	Gordon-Larsen et al. (2006)	Average income in CT	Yes	Yes
Total number of occupied private dwellings	Agreement by senior members	Total number of occupied private dwellings in CT	Yes	Yes
Total number of owned dwellings	Agreement by senior members	Total number of owned dwellings in CT	Yes	Yes
Average value of dwelling	Djietror and Inungu (2007)	Average value of dwelling in CT	Yes	Yes
Total visible minority population	Berrigan and Troiano (2002)	Total visible minority population in CT	Yes	Yes
Total aboriginal identity population		Total aboriginal identity population in CT	Yes	Yes
Total recent immigrants	Agreement by senior members	Total recent immigrants in CT	Yes	Yes
Unemployment rate		Unemployment rate in CT	Yes	Yes
Number of dependents	Agreement by senior members	Average number of children at home per census family in CT	Yes	No

2.6 CVD Mortality

CVD mortality data was obtained from the Ministry of Health and Long-Term Care (2000–2005, $N = 5872$ cases) and used for the present analysis. Causes of death were subsequently classified as: Chronic rheumatic disease (ICD-9 codes: I05-I09), Hypertensive disease (I10-I15), Ischemic heart disease (I20-I25), Pulmonary heart disease and related (I26-I28), Non rheumatic valve disorders (I34-I36), Cardiac arrest (I46), Cardiac arrhythmias (I44-I49), Heat failure and complication, ill-defined heart disease (I50-I51), Cardiomegaly (I51.7), Cerebrovascular diseases (I60-I69), Atherosclerosis (I70), and Aortic aneurysm and dissection (I71-I72). The R96 classification of "Other sudden death, cause unknown" (including "Instantaneous Death" (R96.0) and "Death occurring less than 24 hours from onset of symptoms, not otherwise explained" (R96.1)) were not included, and treated as censored (non-cardiac) events. As such, the mortality data related to CVD death are likely an underestimate of the true total number of mortality cases within the region.

Among these data, 5238 cases had postal code residential information and could be geocoded for spatial analysis. After elimination of postal codes outside of the catchment area, the final analytic sample included 4992 cases. The mortality sample was then spatially linked to the CT boundary file to reveal the total number of CVD-related deaths in each CT. Mortality rates were subsequently calculated by using the total number of deaths divided by total number of population by CT from Statistics Canada. Rates were based on averaged mortality rate for 6 years – 2000 to 2005 – to enable more stable estimates at the CT level. The overall mortality rate of York Region was 74 per 100,000 population (using 2006 census population).

2.7 Geospatial Factors

The "built environment" comprises urban design, land use, and the transportation system and encompasses patterns of human activity within the physical environment. There is currently no consensus as to the relative importance of the built environment and community collective factors in influencing cardiovascular morbidity and mortality. Based on the literature review and discussion with the senior offices at York Public Health Unit, a list of geospatial indicator data was used for representing the neighborhood built environment, including:

- Distance-based accessibility index: the average distance (m) for people to the nearest fitness facilities, hospitals, recreation sites, long-term care facilities, bus stops, sidewalk, trails, bike paths, and green spaces.
- Street network connectivity: the number of street connectivity in each CT.
- Building density: the percentage of building areas in each CT.
- Vegetation cover: the vegetation area percentage in each CT. Remote sensing image processing was applied on Landsat Thematic Mapper (TM) Images, Queen's University Library, 2004, to get the vegetation area in each CT, and the vegetation area percentage was got by dividing vegetation area by CT area.

- Average number of opportunities: average number of opportunities such as fast-food restaurants, convenience stores, and grocery store in each CT.

Multiple independent variables were captured from the CCHS dataset, census and GIS data to account for environmental, epidemiological, demographic, and socioeconomic characteristics. The values of poorer states of health of each variable (i.e., obesity, hypertension, diabetes, heavy drinking, heavy smoking, and sedentary lifestyle) were included within the models for spatial analysis. Table 3 lists and describes these variables.

Table 3 CVD risk factors related to neighborhood built environment extracted from GIS data

Category and indicator	Quality of data (has indicator been used in other research?)	Description of data	Is data available for use?	Selected for analysis?
Urban design (base information)				
Municipal boundaries			Yes	Yes
CTs		Small geographic areas with populations b/w 2500–8000	Yes	Yes
Roads	Saelens et al. (2003)	Files for existing street network in York region	Yes	Yes
Water bodies	Humpel et al. (2004)	Bodies of water	Yes	Yes
Social housing	Agreement by senior members	Rental and subsidized housing	Yes	Yes
Urban design (density)				
Density of buildings	Handy et al. (2002)	Number of buildings per square km	Yes	Yes
Connectivity				
Number of intersections per square area	Frank et al. (2005)	Measure of street connectivity	Yes	Yes
Transportation systems				
Sidewalks	Hoehner et al. (2005)	Indication of pedestrian walkways and pedestrian traffic	Yes	Yes
Roads	Agreement by senior members	Location of motor vehicle routes	Yes	Yes
Hiking trails	Hoehner et al. (2005)	Areas designated for leisure-time activity	Yes	Yes
Biking trails	Hoehner et al. (2005)	Indication of active transportation for leisure; transport-related commute routes	Yes	Yes
Bus stops	Evenson et al. (2009)	Designated bus stops	Yes	Yes

(continued)

Table 3 (continued)

Category and indicator	Quality of data (has indicator been used in other research?)	Description of data	Is data available for use?	Selected for analysis?
Land use designations				
Fast-food locations	Jones et al. (2009)	Restaurants/chains offering high-calorie/nutritionally deficient food	Yes	Yes
Fitness facilities	Hoehner et al. (2005)	Fitness/health facilities within region	Yes	Yes
Tobacco vendors	Agreement by senior members	List of current establishments licensed to sell tobacco products	Yes	Yes
Schools	Saelens et al. (2003)	Location of primary and secondary schools	Yes	Yes
Healthcare facilities – hospitals, LTC	Agreement by senior members	Location of hospitals, long-term care facilities, and healthcare centers	Yes	Yes
Air quality				
Modeling data for air quality	Agreement by senior members	The length of the major roads (km) in that CT allows for an approximation of the CVD burden due to traffic	Yes	Yes
Open space				
Percentage of green space	Coombes et al. (2010)	Percent of land zoned as green space	Yes	Yes
Park locations	Coombes et al. (2010)	Open/free access to designated parks	Yes	Yes
Green fields	Agreement by senior members	Land designated as green space lacking developmental plans	Yes	Yes

2.8 *Statistical Analysis*

Two different spatial statistical techniques were applied to evaluate individual CVD risk factors or outcomes, including Moran's statistic to measure whether there is a significant spatial variation in the rates of CVD mortality and risk factors throughout York Region based on their locations and attribute values and hot spot analysis to see where significant spatial variation was. Ordinary Least Squares regression and Geographically Weighted Regression (GWR) were subsequently applied to determine the contribution of each geographic, demographic, and lifestyle factors on CVD mortality rate. OLS is a global regression method while GWR is a local, spatial, regression method that allows the relationships being modeled to vary across the study area. GWR subsequently constructs separate equations by incorporating the dependent and explanatory variables of features falling within the bandwidth of each target feature.

CVD mortality rate per 100,000 population was used as dependent variable, and population density; percentages of males and females; low education population; average income; total number of occupied private dwellings; average value of dwelling; total visible minority population; aboriginal identity population; total recent immigrants; air quality index (total length of the major roads (km)); distance-based accessibility index (average distance (m)); building density; number of street network connectivity; obesity rate per 100,000 population; diabetes rate per 100,000 population; hypertension rate per 100,000 population; sedentary lifestyle rate per 100,000 population; low consumption of fruit and vegetable rate per 100,000 population; low income rate per 100,000 population; inaccessible to physicians rate per 100,000 population; heavy smoking rate per 100,000 population; heavy drinking rate per 100,000 population; average age; average value of dwelling; unemployment rate; average household size; percentage of rent dwelling; average number of fast-food restaurants, convenience stores, and grocery stores; and average length of time in Canada since immigration were used as independent variables.

3 Results

3.1 Prevalence of CVD Risk Factors

Table 4 describes the prevalence of CVD risk factors by age, sex, education, and location of dwelling (living in urban or rural environment) within the CCHS samples. As expected, younger adults tended to have a better CVD risk profile than older adults, with lower prevalence of hypertension and diabetes. The prevalence of diabetes and hypertension increased with age, and older adults tended to be more inactive and more overweight than younger adults. Indeed, the prevalence of inactivity in 12- to 19-year-olds was 29% but increased to around 50% in 20- to 75-year-olds. Similarly, the overweight rate increased from 9.4% in 12- to 19-year-olds to over 30% after the age of 20 years. These age-related patterns persisted for the prevalence of non-smokers (12–19 years, 88%, vs. 20+ years, <50%) and high consumption of fruits and vegetation (12–19 years, 50.4%, vs. 20–44, <34.8%). Interestingly the heavy drinkers are more popular in young age groups than old groups. The rates of heavy drinkers were 23.9% and 21.6% for the age groups of 12–19 and 20–44, respectively, but this rate has reduced to 3.9% at the age group of 75+.

In general, males had higher rate of physical activity than females. However, over half of males were classified as either overweight or obese, while only one-third of women fell into this category. Compared with males, females had a much higher percentage of non-smokers and non-drinkers with higher consumption of fruits and vegetables. The rate of diabetes was slightly higher in males than in females, while the opposite trend existed in the rate of hypertension.

Overall, the majority of respondents had completed at least their high school degree, were living in an urban setting, and had regular access to a family physician.

Table 4 Prevalence (%) of demographic characteristics for York Region (weighted samples)

		Age group (years)					Sex		Education		Location	
Risk factor		12–19	20–44	45–64	65–74	75+	Male	Female	<High school	≥High school	Urban	Rural
Physical activity (N = 1646)	Inactive	29.0	47.5	51.6	46.4	64.1	40.5	51.9	41.4	47.7	47.2	40.4
	Moderately active	20.6	28.2	27.4	29.6	27.2	26.9	26.7	21.9	28.2	26.5	29.8
	Sufficiently active	50.4	24.2	21.0	24.0	8.7	32.6	21.4	36.6	24.1	26.3	29.8
BMI category (N = 1626)	Normal weight	88.0	59.1	45.5	37.0	50.0	48.0	66.2	67.8	54.8	58.5	48.2
	Overweight	9.4	31.0	37.5	39.4	43.0	39.0	23.7	22.9	33.1	29.8	42.7
	Obese	2.6	9.9	16.9	23.6	7.0	13.0	10.1	9.3	12.1	11.8	9.1
Smoking status (N = 1619)	Heavy smokers	2.9	19.0	14.7	8.5	5.3	15.6	12.0	9.3	15.0	13.0	20.2
	Former smokers	9.1	37.2	44.0	43.4	47.4	41.1	31.4	22.4	39.8	35.7	38.0
	Non-smokers	88.0	43.8	41.3	48.1	47.4	43.2	56.5	68.3	45.2	51.3	41.7
Drinking status (N = 1242)	Heavy drinkers	23.9	21.6	14.0	5.5	3.9	25.8	8.9	16.5	17.6	16.8	23.3
	Few drinks per week	27.2	29.4	17.4	7.7	5.2	26.5	19.3	20.3	23.2	23.1	21.8
	Non-drinkers	48.9	49.1	68.6	86.8	90.9	47.7	71.7	63.3	59.2	60.1	54.9
Income (N = 1681)	Low income	3.6	3.2	4.5	7.8	13.7	3.4	5.7	8.3	3.6	4.6	5.4
	High income	96.4	96.8	95.5	92.2	86.3	96.6	94.3	91.7	96.4	95.4	94.6
Fruit and vegetable consumption (N = 1598)	Low consumption	49.6	63.2	57.0	54.2	51.0	63.5	53.4	55.9	59.1	58.4	56.6
	High consumption	50.4	36.8	43.0	45.8	49.0	36.5	46.6	44.1	40.9	41.6	43.4
Family doctor (N = 1681)	No family doctor	4.0	9.9	4.5	4.7	2.6	8.3	5.3	7.4	6.6	6.5	8.4
	Has a family doctor	96.0	90.1	95.5	95.3	97.4	91.7	94.7	92.6	93.4	93.5	91.6
Comorbidities	Diabetes (N = 1679)	0.0	0.5	7.9	14.7	14.5	4.9	3.8	6.0	3.8	4.2	5.4
	Hypertension (N = 1674)	0.8	2.9	21.1	43.0	47.9	12.0	14.6	16.2	12.6	13.5	12.7

The group without a high school degree had a slightly higher rate of diabetes and hypertension than those with a high school degree. Here again, higher education was associated with a higher income, but higher rates of inactivity, overweight or obesity, and smoking and drinking. Finally, on average, those who lived in rural areas had higher physical activity, but lower income than those in urban areas. Rural areas also had higher prevalence of self-reported overweight and heavy smokers and drinkers. The rate of diabetes was only marginally higher in rural areas than in urban, where hypertension was slightly higher.

3.2 Hot Spot Analysis of CVD Mortality and Risk Factor Rate

Within the entire region, a weak spatial autocorrelation existed for CVD mortality rate (Moran's I Index < 0.1, $p < 0.01$). For CVD risk factors, random dispersal was also observed for diabetes and hypertension, rates of physical inactivity, low income, and respondents without a regular medical doctor. On the other hand, several risk factors showed significant but weak spatial autocorrelation, including obesity (Moran's I Index = 0.2, $p < 0.01$), alcohol consumption (Moran's I Index = 0.2, $p < 0.01$), and regular cigarette smoking (Moran's I Index = 0.2, $p < 0.01$).

For rates of CVD mortality and risk factors (obesity, heavy drinking, and smoking) in which a significant weak spatial autocorrelation was found, hot spot analysis was subsequently applied to identify where these clusters were located. Spatial clusters of high values (hot spots) were identified in the northern regions, while spatial clusters of low values (cold spots) were identified in the southern region, indicating regional differences in risk factors. (See Fig. 3b for an example.)

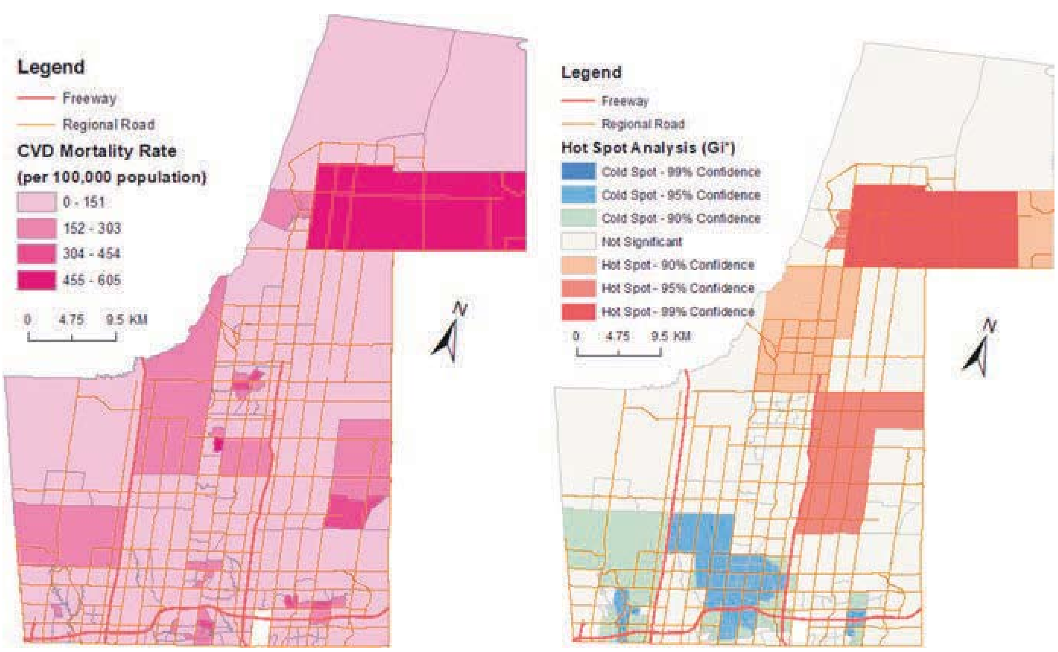

Fig. 3 CVD mortality rate (left) and its hot spot analysis result (right) at census tract level in York Region

Table 5 Local parameter estimates of regression analysis of CVD mortality rates with significant variables in OLS and GWR analysis

Variable	Ordinary Least Squares (OLS)		Geographically Weighted Regression (GWR)	
	Parameter	Standard error	Average parameter	Average standard error
Intercept	5.0917	0.9383	−0.4901	0.2797
Average age	0.0114	0.0055	0.0118	0.0065
Average length of time in Canada since immigration	−0.1141	0.0560	−0.1357	0.0668
Total recent immigrants	−0.1974	0.0500	−0.2129	0.0619
Distance-based accessibility index	−0.1341 (n.s.)	0.1077	−0.1602	0.1298
Building density	0.3462	0.0492	0.3521	0.0588
Average number of opportunities	0.3606	0.0719	0.3432	0.0878
Number of street network connectivity	−0.1590 (n.s.)	0.0844	−0.1016	0.1020

All variables included in the OLS model were re-assessed in GWR analysis, and only variables significant at the $p < 0.05$ levels were included in this table

3.3 OLS and GWR Regression Analysis

Table 5 lists the risk factors which were statistically significant ($p < 0.05$) for CVD mortality in classical ordinary least square (OLS) regression analysis and/or geographical weighted regression analysis (GWR). For CVD mortality rate, building density, average age and average number of fast-food restaurants, convenience stores, grocery store and recreational activities in each CT were positively associated with CVD mortality rate, and average length of time in Canada since immigration and total recent immigrants were negatively associated with mortality rate.

Compared with OLS, GWR analysis reports two additional parameter estimates (distance-based accessibility index and number of street network connectivity) which were statistically significant for CVD mortality rate, indicating a significant association between neighborhood environmental attributes and CVD local mortality rate. Overall, a greater variance in CVD mortality rate was observed in the GWR than OLS analysis (63% vs. 51%, respectively).

4 Discussion and Conclusion

This study shows that regional differences existed in risk factors and that several built environmental attributes – including high density of buildings, the long distance to the nearest fitness facilities, hospitals, recreation sites, long-term care facilities, bus stops, sidewalk, trails, bike paths, and green spaces – collectively increased CVD risk. These results suggest that neighborhood attributes such as building density, street connectivity, and the availablity and safety of recreational space and facilities that improve neighborhood walkability, biking, and other leisure activities, should be community-level targets for reducing the burden of CVDs. These findings are consistent with other studies on how safe pedestrain trails and recreational facilities would encourage walking and other physical activities to reduce the CVD risk (Kaczynski and Henderson 2008; Arango et al. 2013; Ferdinand et al. 2012; Malambo et al. 2016).

Aside from age, the most common individual-level CVD risk factors (e.g., obesity, hypertension, diabetes, heavy drinking, heavy smoking, sedentary lifestyle, low income, low consumption of fruit and vegetable, no physician access) involved in this study did not significantly contribute to the spatial variation of mortality rates at the CT level within our sample catchment area.

Preliminary analyses also found that high accessibility to fast-food restaurants, convenience stores, and grocery stores overall are associated with an increse in CVD risk. While the findings for grocery stores are not generally supported by other literature, it has been suggested that greater accessibility to fast food restaurants may incentivize people to choose unhealthy dietary or visit convenience stores or fast food restaurants, thus increasing the chance of consuming unhealthy foods may in turn increase CVD risk (Inagami et al. 2006; Burns and Inglis 2007).

This study also observed that neighborhoods with higher proportions of new immigrants tended to have higher rates of CVD and that time since immigration was inversely related to CVD risk in general. While differences in modifiable lifestyle factors are recent and longer-term immigrants have been shown (Langellier et al. 2012), the finding of regional hot spots for CVD outcomes has an important implication on the health policy focusing on the social determinant of health within newcomer groups.

Moreover, the results of GIS-based geospatial analyses suggest that health promotion strategies may need to be tailored to specific regions within a municipality, to account for variation in demographics and risk factor clusters. While OLS regression may be used to identify factors that are associated with mortality, accounting for shared features of the built environment can capture variations in health risk that would normally be left unaccounted for. When taken together, this method of analysis was able to identify variables associated with CVD mortality rate, while also using spatial analysis to identify regional clustering and hot/cold spots for intermediate risk factors.

These analyses demonstrate that incorporating multiple types and levels of data (i.e., variables from one survey provide the individual-level covariates, while GIS data is pooled to provide information for the CT) is feasible and will increase the variance in CVD mortality that can be accounted for. While these analyses were able to identify areas of hot/cold spots, clusters, and determine if spatial autocorrelation was present, results from this analysis suggest that any single method of geographic analysis may be insufficient to identify regions that are at greater risk of CVD outcomes. As the data for this study represent multiple waves of surveillance, the analyses and maps produced represent a period estimation of surveillance, as opposed to a specific point in time.

5 Limitations

As with any approach, this analysis must be interpreted in light of the limitations we identified while designing and evaluating this CVD geospatial surveillance system. For one, the analysis was based on a small sample of risk factor data (CCHS Cycle 3.1 2005). There were 1681 respondents, and not all data related to the built environment was obtainable for the York Region health unit area. While the CCHS did contain six-digit postal codes (the smallest geocoding available for CCHS), more precise address information (street and unit number) were not available. Using 2000–2005 morbidity data, 2003–2009 mortality data, 2006 census data, and 2005 CCHS data for indicators results in the data overlapping but not completely matching up. Moreover, there is no way to account for people moving in and out of the region, length of stay, or the lag time between people living in a particular region and the changes to their behavior or development of CVD-related outcomes. In this analysis, only one cycle of CCHS data was used. Due to the limitation of sampling size in one cycle, some CTs end up with few or no samples, which may lead to some biases on the robustness of analysis results. Multiple cycles of CCHS should be tested in the future to validate the results from this study, panning multiple urban, suburban, and rural regions.

It should also be noted that CVD and CVD mortality rate are highly age-dependent. Age-adjusted CVD mortality rate would be a better dependent variable. In addition, only GWR was tested to explore the impact of different factors on spatial variation of mortality rate due to the weak global spatial autocorrelation in the dataset. Other spatial regression models should be tested and used in the future for datasets showing strong spatial autocorrelation (Delmelle et al. 2016). In light of data quality and availability issues, the geospatial results described in this paper are exploratory. Public health units with more extensive GIS data sources could potentially see stronger effects between built environment indicators and CVD risk factors, morbidity, and mortality.

The findings from studies that explored neighborhood built environmental attributes and their association with CVD risks and major CVD outcomes will help guide policy-makers on the built environmental, transportation, and health planning to improve intervention programs at the local level. The spatial analyses framework outlined in this paper would be feasible to administer in other public health units. With analyses using data collected over multiple years, the surveillance system could detect trends with CVD risk factors through use of routinely collected data from provincial and federal health agencies. These databanks would be compiled largely based on aggregating local sources of health data from hospitals, thus representing the population of the local region.

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Lei Wang received the Ph.D. degree in geography from York University. He is an associate professor at Institute of Remote Sensing and Digital Earth, Chinese Academy of Sciences, China. He was a postdoctoral fellow at the Department of Geography, Queen's University. His research interests include geospatial analysis, digital earth, digital ocean and internet GIS.

Chris I. Ardern is an Associate Professor in the School of Kinesiology and Health Science at York University, and Affiliated Investigator at Southlake Regional Health Centre. His primary research interests include the epidemiology of physical activity, obesity, and cardiometabolic risk. Most recently, his work has focused on the use of risk algorithms, behavioural profiling, and geospatial analysis for the identification of high-risk subgroups. Much of this work involves the analysis of routinely collected administrative and clinical data to examine patterns of movement behaviors and their interactions in relation to obesity phenotypes.

DongMei Chen received the B.A. in economic geography from Peking University, China; the master in GIS and remote sensing application from the Institute of Remote Sensing Application, Chinese Academic of Science; and the Ph.D. in geography from the joint doctoral program of San Diego State University and University of California at Santa Barbara. She is currently a professor at the Department of Geography and Planning, Queen's University, Canada. Her research interest focuses on spatial data analysis and modeling, GIS, remote sensing technology, and their applications in environmental management and public health. More details about Dr. Chen and her research laboratory can be found at gis.geog.queensu.ca.