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Analysis of community deaths during the catastrophic 2021 heat dome

Early evidence to inform the public health response during subsequent events in greater Vancouver, Canada

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Background: British Columbia, Canada, was impacted by a record-setting heat dome in early summer 2021. Most households in greater Vancouver do not have air conditioning, and there was a 440% increase in community deaths during the event. Readily available data were analyzed to inform modifications to the public health response during subsequent events in summer 2021 and to guide further research.

Methods: The 434 community deaths from 27 June through 02 July 2021 (heat dome deaths) were compared with all 1,367 community deaths that occurred in the same region from 19 June through 09 July of 2013–2020 (typical weather deaths). Conditional logistic regression was used to examine the effects of age, sex, neighborhood deprivation, and the surrounding environment. Data available from homes with and without air conditioning were also used to illustrate the indoor temperatures differences.

Results: A combined index of material and social deprivation was most predictive of heat dome risk, with an adjusted odds ratio of 2.88 [1.85, 4.49] for the most deprived category. Heat dome deaths also had lower greenness within 100 m than typical weather deaths. Indoor temperatures in one illustrative home without air conditioning ranged between 30°C and 40°C.

Conclusions: Risk of death during the heat dome was associated with deprivation, lower neighborhood greenness, older age, and sex. High indoor temperatures likely played an important role. Public health response should focus on highly deprived neighborhoods with low air conditioning prevalence during extreme heat events. Promotion of urban greenspace must continue as the climate changes.

Keywords: Heat dome; All-cause mortality; Neighborhood deprivation; Urban heat island; Greenness

Introduction

In early summer 2021, the province of British Columbia (BC), Canada, experienced an unprecedented heat dome. Rapid attribution analyses found that this historic event would have been virtually impossible without anthropogenic climate change.[1] Hundreds of local temperature records were broken, often on consecutive days at the same location. For example, the small town of Lytton in the Fraser Canyon broke national temperature records on June 27 (46.6°C), June 28 (47.5°C), and June 29 (49.6°C) before being destroyed by wildfire on June 30. In the greater Vancouver metropolitan area, the heat dome started to build on June 24, and increasingly higher temperatures were observed until June 28 (Figure 1). This period was also characterized by very high overnight temperatures, and near-peak daylight hours for the region (sunrise at ~05:10 and sunset at ~21:20). Most homes in greater Vancouver do not have any type of air conditioning,[2] so the extreme outdoor temperatures and intense solar radiation led to very high indoor temperatures with little overnight cooling (Figure 2). The stagnant air mass and solar radiation also contributed to high ground-level ozone concentrations, and the region was under an air quality advisory throughout most of the heat dome.

In addition to the media coverage around temperature records, there were widespread reports of impacts on human health. Use of hospital emergency rooms was high, emergency health services received a record number of calls, and hundreds of sudden deaths were reported to the BC Coroners Service

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Data availability: The vital statistics data used for this study cannot be made publicly available, but access can be requested from the BC Vital Statistics Agency. Other data are available from CANUE (Canadian Urban Environmental Health Research Consortium) upon request.

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What this study adds

Extreme hot weather often goes unrecognized as a health threat in temperate climates. This study is the first to report on impacts of the historic 2021 heat dome in a large urban area. It uses available data to describe indoor temperatures in one illustrative home without air conditioning, confirms the role of deprivation as a risk factor for mortality, and highlights the protective effects of greenspace during acute extreme events. It also demonstrates the utility of readily available data for analyses that can inform rapid shifts in public health policy. Evidence generated here was used to modify the public health response during two subsequent events in summer 2021.

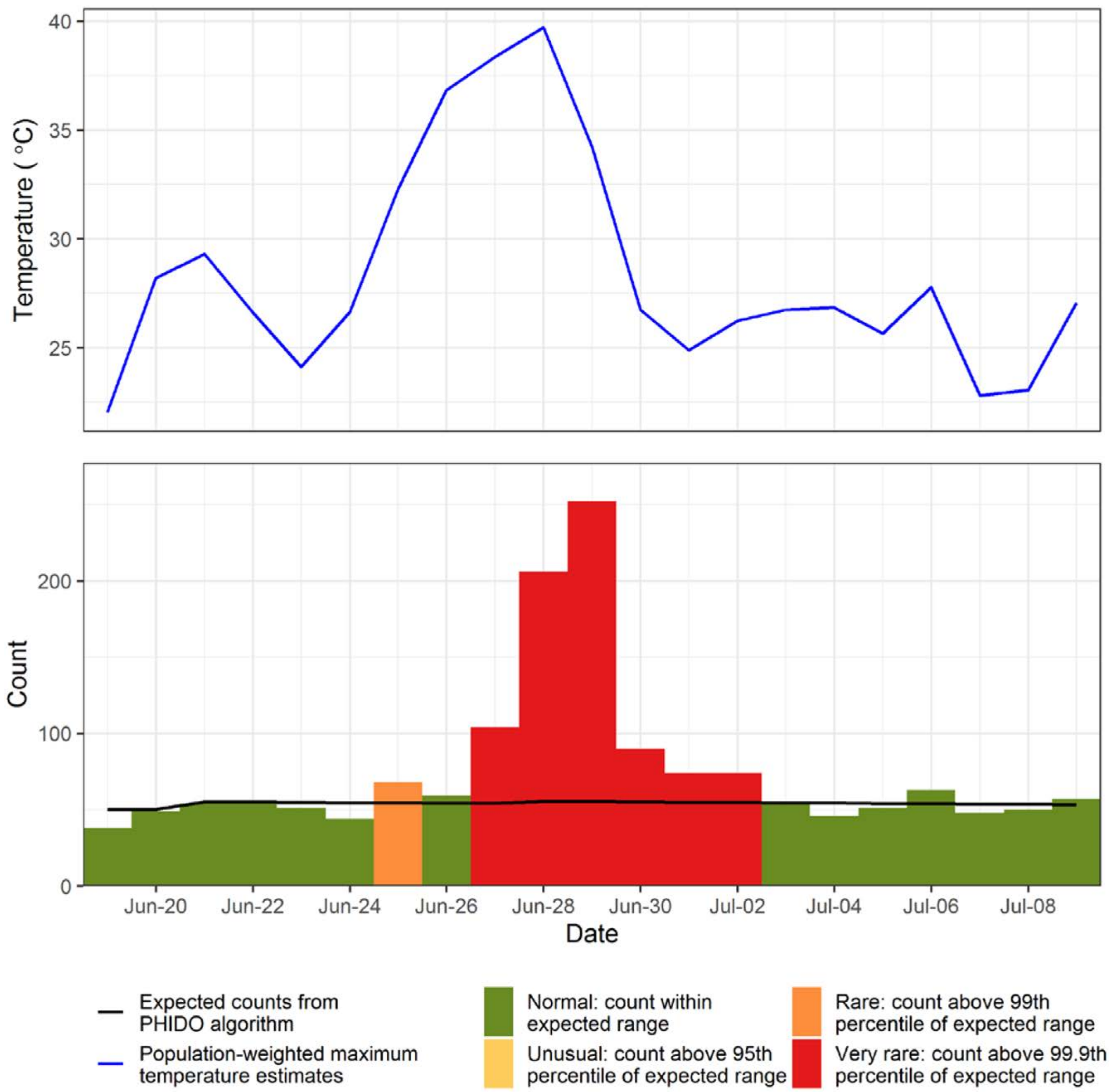

Figure 1. Time series of daily observed mortality (bars) and daily population-weighted maximum temperature (blue line) estimates for greater Vancouver during the 2021 heat dome. Counts are coloured according to their deviation from expected values (black line), as calculated with the PHIDO algorithm used by the BC Centre for Disease Control. Heat dome deaths were drawn from the 6 days coloured in red, which include June 27 through July 2. PHIDO, Public Health Intelligence for Disease Outbreaks.

for investigation.[3] Catastrophic mortality during heat domes has been reported in other cities such as Paris during the 2003 event,[4] and Moscow during the 2018 event.[5] The most analogous extreme heat event in greater Vancouver occurred during the summer of 2009 and was associated with an estimated excess of 110 deaths in the region. Initial case-only analyses with limited data found that many deaths occurred in the community, and that increased risk was associated with the 65–74 age range, higher population density, and neighborhoods with a higher proportion of individuals under the Canadian low-income cutoff threshold.[6]

The BC Centre for Disease Control (BCCDC) is a public health agency with a mandate to conduct applied research and surveillance to support evidence-based policy in the province. Following the 2009 extreme heat event, our team at the BCCDC was granted access to enhanced data for surveillance of heat-related mortality so that policy-relevant evidence could be generated from future events more rapidly. Most importantly, we were given near-real-time access to the 6-digit postal code of death for all decedents, allowing linkage with known care facilities and with spatial data that may be associated with risk. Further analyses on the 2009 event using these enhanced data found that neighborhood deprivation and lack of greenness were significantly associated with odds of mortality.[7] Here we apply what we learned from the 2009 event[6,7] to examine factors associated with hundreds of community deaths during the 2021 heat dome. Although much more detailed study will be required over time, our objectives were to (1) characterize demographic and spatial risk factors associated with heat dome mortality; (2) inform modification of the public health response during subsequent events in summer 2021; and (3) generate early evidence for guiding further inquiry into the heat dome impacts.

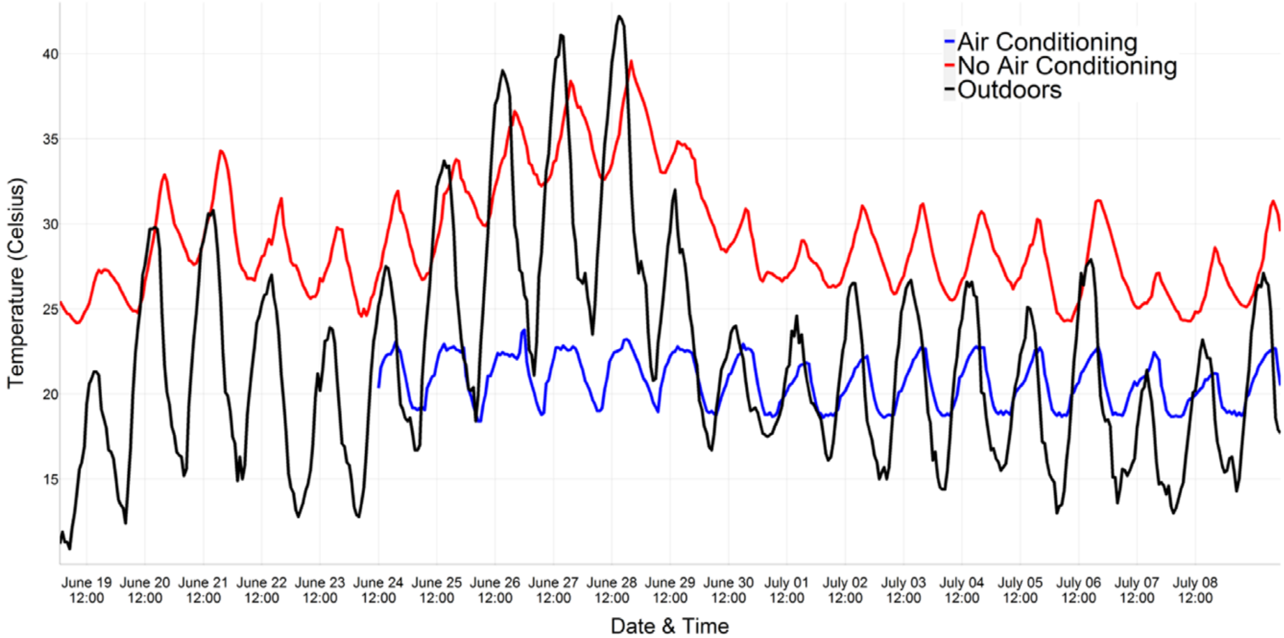

Figure 2. Hourly temperature measurements during the 2021 heat dome in greater Vancouver. These data come from the inland municipality of Abbotsford, where temperatures are usually at least 5°C higher than in the coastal areas. The outdoor measurements (black line) were taken from the weather station at Abbotsford International Airport. The indoor measurements (blue and red lines) were accessed through the *ecobee Donate Your Data* program (https://www.ecobee.com/donate-your-data/), which allows its internet-enabled thermostat owners to make their data anonymously available for research purposes. There were 11 homes with *ecobee* data in Abbotsford. The red line shows the worst-case scenario home without air conditioning, demonstrating how temperatures can build to dangerously high levels during an extreme heat event. The blue line shows the best-case scenario home with air conditioning, though data were missing for the days before the heat dome.

Methods

Study area

The greater Vancouver metropolitan area is located on the southwestern coast of BC, at the Fraser River delta. The region comprises 24 municipalities with a 2020 population of approximately 3.05 million people. The climate is typically temperate, with mild winters and summers. The offshore Pacific breeze and surrounding Fraser River moderate temperatures throughout the region in all seasons.[8] Summer days with high temperatures over 30°C are rare near the coast, though temperatures are usually about 5°C higher inland.[9] In 2018, BC Hydro published a report indicating that only 34% of all homes in BC had some type of air conditioning, and that most were in the central interior region where higher summer temperatures are common.[2]

Mortality data

The BCCDC receives daily data from the BC Vital Statistics Agency. Most deaths are registered within 21 days, but sudden or accidental deaths under investigation by the BC Coroners Service can take longer. The data described here were extracted on August 10, 2021, and they exclude any deaths during the heat dome that were registered after that date. The vital statistics data include some fields that are populated on the date the death is registered, and some that can take weeks or months to complete. The fields completed immediately upon registration include age, sex, date of death, date of registration, local health area (20 in greater Vancouver, see Figure 3), and 6-digit postal code of death. The fields completed in the weeks or months following registration include underlying cause of death, contributing causes of death, and specific setting of death (private home, hospital, outdoors, etc.). Only the fields completed immediately upon registration were used in these early analyses.

Heat dome deaths

The BCCDC also maintains a database of all hospitals, long-term care facilities, and assisted living facilities in the province, including their 6-digit postal codes. By linking the 6-digit postal code of death in the vital statistics data with the 6-digit postal codes in the care facilities data, we can separate deaths that occurred at care facilities from those we assume to have occurred in the community. The heat dome group included all deaths at age 50+ years that occurred in the community on June 27 through July 2, 2021. These 6 days represent the period when regional mortality was most significantly elevated above expected during the heat dome (Figure 1).

Deaths in those aged <50 years were excluded to minimize the influence of the ongoing overdose emergency in BC.[10] Overdose deaths could not be directly identified from the vital statistics data for the heat dome group because cause of death information is not available for several weeks or months after initial registration of the death. However, deaths due to overdose from 2013 to 2020 accounted for 59% of all community deaths in greater Vancouver for those aged <50 years, compared with 11% for those aged 50+ years. Given our objective to focus on community deaths caused by the heat dome, we used age as a proxy to reduce the number of deaths likely to be attributed to overdose. Furthermore, risk of heat-related mortality is highest in older adults.[11]

Typical weather deaths

The comparison group included all community deaths in those aged 50+ years from June 19 to July 9 of 2013–2020. These dates were chosen to span the same timeframe as the heat dome (Figure 1) during more typical summers and to include at least three typical weather deaths for each heat dome death in the analyses. Deaths due to overdose in those aged 50+ years were also excluded, as were any deaths with pending cause of death information. Deaths due to overdose were identified using the

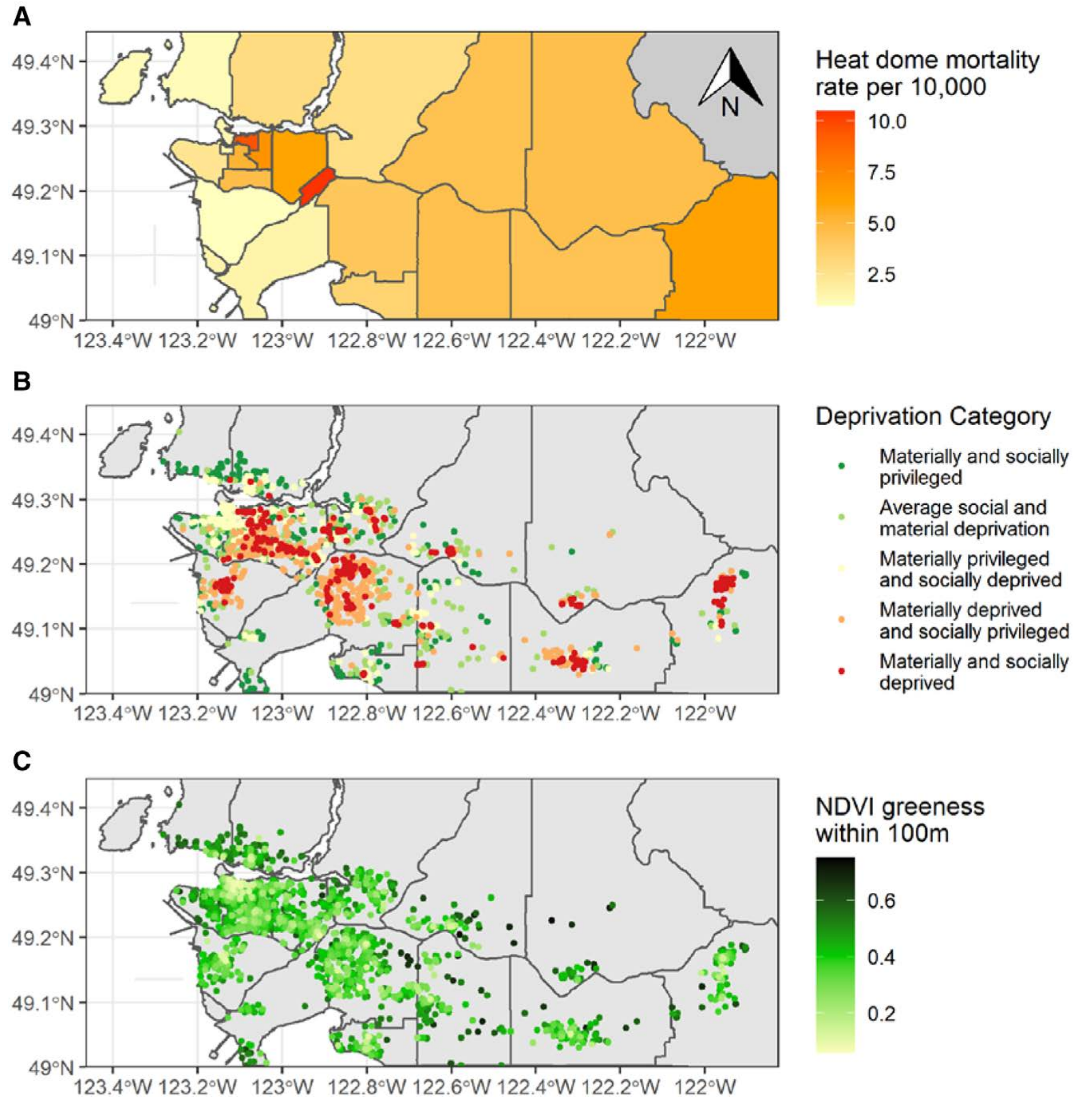

Figure 3. Maps of the heat dome community mortality rate (A), locations in the material and social deprivation categories (B), and greenness within 100 m (C). The crude mortality rate is shown for those aged 50+ in each of the 20 local health areas included in the study. Deprivation categories are shown at the postal code locations for all deaths included in the study, whether they occurred during the heat dome or the typical weather period. Likewise, the NDVI greenness values are shown at the postal code locations of all study subjects. NDVI, normalized difference vegetation index.

International Classification of Disease, 10th Revision (ICD-10) codes used by the BC Provincial Overdose Cohort (T401-T406)[12] and pending cause of death was identified by the code R99.

Potentially predictive neighborhood variables

The 6-digit postal code of death was used to link heat dome and typical weather deaths with multiple spatial datasets to assess the effects of deprivation and the surrounding environment. All of the data were downloaded from the Canadian Environmental Health Research Consortium (CANUE), which aims to develop standard measures of environmental factors so that researchers can use consistent and analysis-ready data to examine how the environment affects human health.[13] All data provided by CANUE are extracted by 6-digit postal code, which was used to join the vital statistics data with the spatial variables described later.

Neighborhood deprivation was assessed with the Material and Social Deprivation Indices (MSDI) developed by the Institut National de Sante Publique du Quebec (INSPQ) using national census data. The indices are constructed using six indicators of economic and social status from the Statistics Canada National Household Survey, such as proportion of the population without a high school diploma, and proportion of the population living alone.[14] We extracted the most recent regional quintiles from the 2016 census and created a combined deprivation grouping using the first strategy recommend in the MSDI user guide[15] to create the following five categories: (1) materially and socially privileged; (2) average material and social deprivation (reference category); (3) materially privileged but socially deprived; (4) materially deprived but socially privileged; and (5) materially and socially deprived.

The surrounding environment was assessed using information about greenness, building density, and distance from features such as major roads and water sources. For greenness, we selected the mean growing season normalized difference vegetation index (NDVI) from Landsat, which ranges from values of 0 to 1 over land. Values less than 0.2 indicate barren surfaces, values from 0.2 to 0.4 indicate grassland or brush, and values greater than 0.4 indicate increasingly lush vegetation.[16,17] For building density, we extracted the percent of area covered by building footprints as generated by CANUE.[18] Both the greenness and building density data were available for buffer areas ranging from 100 to 1,000 m. We used the available road and water proximity data to create variables indicating distance from any highway or major road, and distance from any major body of water (ocean, lake, or river). All spatial variables were extracted for the 2016 census year except for building density, which was only available for 2019.

Temperature data

The BCCDC generates gridded estimates of daily maximum air temperature across the province at a resolution of approximately 769 m. Temperatures measured at all available monitoring stations are spatially interpolated with thin plate smoothing splines, accounting for elevation.[19] These interpolations have a mean absolute error of approximately 1.6°C and are intended for surveillance purposes, not to provide accurate exposure assessment for any specific location. However, they are helpful for characterizing temperatures across large areas, and differences in overall temperature exposure between the heat dome and typical weather groups. Data were extracted by 6-digit postal code for the day of death and two prior days to calculate a 3-day average. In addition, the *ecobee Donate Your Data* program (https://www.ecobee.com/donate-your-data/) allows its internet-enabled thermostat owners to make their data anonymously available for research purposes. We accessed all data available for the inland municipality of Abbotsford (11 homes) to illustrate indoor temperatures differences between the best-case scenario home with air conditioning and the worst-case scenario home without air conditioning.

Statistical analysis

All community deaths during the 2021 heat dome were compared with all community deaths on more typical summer days in 2013–2020. The heat dome deaths were not matched to the typical weather deaths, but all analyses were stratified by the 20 local health areas in greater Vancouver so that comparisons were made within the same smaller geographic areas. The crude and adjusted odds of mortality associated with age, sex, deprivation, and surrounding environment were estimated using simple and multiple conditional logistic regression, respectively. Preliminary univariate analyses were used to select the best-fitted buffer sizes for the greenness and building density variables. We report the odds ratios (OR) and their 95% confidence intervals (95%CI) for the crude regression models and for the best-fitted multiple regression model based on the lowest value of the Akaike Information Criterion (AIC)[20] using backward stepwise regression. All analyses were conducted in the R statistical computing environment, version 4.0.3.[21]

Results

Mortality impacts of the heat dome

The BCCDC uses an in-house anomaly detection algorithm called PHIDO (Public Health Intelligence for Disease Outbreaks) to compare daily observed counts with expected values for multiple health outcomes. Estimates from PHIDO and the Farrington method[22] are similar, but Farrington does not accommodate daily data. Analyses from PHIDO show that daily mortality was significantly elevated above expected for a 6-day period during the heat dome, with the largest impacts on June 28 and 29 (Figure 1). The date with the highest maximum temperature was June 28, but the mortality impacts continued for three days after temperatures returned to baseline, which has also been observed elsewhere.[4,5] There was no clear evidence of a mortality deficit in the days following the heat dome. The PHIDO expected count for all-cause mortality during the 6-day period was 330 deaths, of which 80 were expected to occur in the community among those aged 50+ years. Data from the inland municipality of Abbotsford show that the worst-case scenario home without air conditioning had steadily increasing indoor temperatures between 30°C and 40°C during the heat dome, with little overnight cooling (Figure 2).

Heat dome and typical weather deaths

At the time of data extraction there were 802 deaths registered in greater Vancouver for the 6-day heat dome period from June 27 through July 2, 2021. Of these, 336 (41.9%) were matched to care facilities and 466 (58.1%) were assumed to occur in the community. We excluded 32 deaths in those aged <50 years, leaving 434 heat dome deaths in the study. When compared with the 80 community deaths expected during the heat dome, this represents a 440% increase. The number of deaths within each of the 20 local health areas ranged from 3 to 63, and the crude mortality rate in those aged 50+ ranged from 0.9 to 10.2 per 10,000 population (Figure 3).

There were 7,908 deaths in greater Vancouver during the typical weather periods (June 19 though July 9, 2013–2020). Of these, 6,042 (76.4%) were matched to care facilities and 1,866 (23.6%) were assumed to occur in the community. We excluded 349 deaths in those aged <50 years and 154 deaths due to overdoses or pending causes in those aged 50+ years, leaving 1,363 typical weather deaths for the analyses. The number of deaths within each of the 20 local health areas ranged from 21 to 196, and there were at least two typical weather deaths per each heat dome death in 17 of the 20 local health area strata.

Descriptive summary

The mean (range) 3-day local temperature estimate for the heat dome deaths was 36.3°C (24.4–41.6), compared with 25.0°C (14.9–32.4) for the typical weather deaths. These stark differences clearly indicate the relative severity of the heat dome for this early summer period. The heat dome had a higher proportion of female decedents, and a higher proportion of decedents in the 65–84 age categories. Only 6.2% of the heat dome deaths were in the materially and socially privileged group (category 1), compared with 13.4% of typical weather deaths. On the other hand, 28.1% of heat dome deaths were in the materially and socially deprived group (category 5), compared with 14.9% of typical weather deaths. The proportions were more balanced across the intermediate three groups (Table 1).

For all variables related to the surrounding environment, the heat dome deaths had values that were consistent with urban heat island effects, where ambient temperatures are magnified by materials such as asphalt and concrete.[23] The heat dome deaths had lower surrounding greenness and higher building density. They were also closer to major roads and further from large bodies of water (Table 1). When the between-variable relationships were examined across all 1,797 deaths (434 heat dome deaths and 1,363 typical weather deaths), neighborhood deprivation was significantly associated with all variables except for age category and sex (Table 2).

Table 1.

Summary statistics for deaths during the heat dome and the typical weather comparison period

	Heat dome	Typical weather
N	434	1363
Mean 3-day maximum temperature (SD)	36.3 (3.7)°C	23.0 (3.3)°C
Age category		
<65 years	18.4%	23.8%
65–74 years	25.6%	22.8%
75–84 years	29.0%	24.0%
85+ years	27.0%	29.3%
Sex		
Female	54.6%	43.3%
Male	45.4%	56.7%
Combined material and social deprivation index		
1—materially and socially privileged	6.2%	13.4%
2—average material and social deprivation	9.7%	15.0%
3—materially privileged but socially deprived	20.5%	20.0%
4—materially deprived but socially privileged	21.2%	19.7%
5—materially and socially deprived	28.1%	14.9%
No data	14.3%	17.0%
Surrounding environment		
Mean greenness within 100 m (SD)	0.358 (0.105) unitless	0.386 (0.113) unitless
Mean building footprint within 1 km (SD)	16.2 (5.2)%	15.4 (6.3)%
Mean distance from major road (SD)	218 (263) m	262 (299) m
Mean distance from large water body (SD)	1,205 (687) m	1,083 (688) m

Mean and standard deviation (SD) values are presented for continuous variables along with their units, and proportions are presented for categorical variables.

Conditional logistic regression models

The results of the crude models were consistent with patterns observed in the descriptive summaries. All variables were significantly associated with the odds of mortality during the heat dome. Compared with the average deprivation category, odds of mortality were significantly elevated for the following groups: materially privileged but socially deprived; materially deprived but socially privileged; and both materially and socially deprived, with the biggest effects in this last category (Table 2). The crude OR [95%CI] for the materially and socially privileged group was 0.80 [0.47, 1.38], though the effect was not significantly protective. The best-fitted multiple regression model included only age category, sex, deprivation, and surrounding greenness within 100 m (Table 3).

The multiple regression model showed that odds of mortality during the heat dome were highest for the materially and socially deprived group, with an OR [95%CI] of 2.88 [1.85, 4.49] when adjusted for age category, sex, and neighborhood greenness. The adjusted effects were also significant for the materially deprived but socially privileged group and elevated for the materially privileged but socially deprived group. Most effect estimates remained relatively consistent between the crude models and the adjusted model, though the adjusted effects of age category were increased, and the adjusted effects of greenness were decreased (Table 2). Even with the greenness variable removed, none of the other surrounding environment variables remained significant in multiple regression models adjusted for age, sex, and deprivation.

Discussion

The combined deprivation index was most strongly associated with odds of death during the heat dome, followed by age category, sex, and surrounding greenness. These findings are striking, but not surprising. Material deprivation is associated with risk factors such as lack of air conditioning, and social deprivation is associated with risk factors such as living alone. Indeed, females may have been at higher risk during the heat dome because they are more likely to live alone in older age.[24] However, neighborhood deprivation is also associated with underlying health status,[25] so the variable may be a proxy for comorbidities that cannot be assessed with vital statistics data. Future work is needed to evaluate the effects of conditions such as diabetes, heart disease, mental illness, substance dependency, limited mobility, and dementia. Such analyses require complex linkages between multiple data sources and cannot generally be completed within weeks of an event.

The protective effects of surrounding greenness within 100 m were clear, even after adjustment for neighborhood deprivation. Green spaces and tree canopy can reduce the impacts of the urban heat island effect through evaporative cooling and shading, which we have consistently shown in other studies.[26–28] Increased urban greenness has long been proposed as one approach to mitigating the harmful effects of climate change,[29] but very few other studies have reported on its acute protective effects during specific extreme heat events.[7] Unfortunately, the NDVI greenness metric used here is difficult to interpret in ways that are meaningful to inform public health policy.[30] Future work is needed to understand the impacts of more concrete indicators, such as the number of surrounding trees and their canopy area, or the impacts of different vegetation types.

Beyond surrounding greenness, none of the other environmental variables remained significant in models adjusted for age category, sex, and deprivation. Recent work has shown how heat island intensity covaries with measures of deprivation,[31] which was also evident in our data. More deprived neighborhoods were significantly less green, more dense, closer to major roads, and further from large bodies of water (Table 2). Given these underlying relationships between the predictive variables, the persistent protective effect of greenness is even more important.

Table 2.

Relationships between the independent variables for all 1797 deaths included in the analyses (434 heat dome deaths and 1363 typical weather deaths)

	Age category	Sex	Social and material deprivation	Greenness within 100 m	Building footprint within 1 km	Distance from major road	Distance from large body of water
Age category	–	**<0.001**	0.13	**0.001**	0.41	0.23	0.70
Sex	**<0.001**	–	0.12	0.64	0.61	0.99	0.46
Social and material deprivation	0.13	0.12	–	**<0.001**	**<0.001**	**<0.001**	**<0.001**
Greenness within 100 m	**0.001**	0.64	**<0.001**	–	**<0.001**	**<0.001**	0.91
Building footprint within 1 km	0.41	0.61	**<0.001**	**<0.001**	–	**<0.001**	**<0.001**
Distance from major road	0.23	0.99	**<0.001**	**<0.001**	**<0.001**	–	0.06
Distance from large body of water	0.70	0.46	**<0.001**	0.91	**<0.001**	0.06	–

The *P* value is indicated for the Chi-squared test (categorical vs. categorical variables), analysis of variance (categorical vs. continuous variables), or Pearson's correlation coefficient (continuous vs. continuous variables). Statistically significant results ($\alpha = 0.05$) are shown in bold.

Table 3.

Results of simple (crude) and multiple (adjusted) conditional logistic regression models of the heat dome deaths compared with the typical weather deaths

Variable	Simple regression crude OR [95% CI]	Multiple regression adjusted OR [95% CI]
Age category		
<65 years	Reference	Reference
65–74 years	1.50 [1.07, 2.10]	1.71 [1.19, 2.52]
75–84 years	1.67 [1.20, 2.32]	1.83 [1.26, 2.65]
85+ years	1.34 [0.94, 1.81]	1.55 [1.06, 2.26]
Sex		
Male	Reference	Reference
Female	1.61 [1.29, 2.01]	1.59 [1.23, 2.04]
Combined material and social deprivation index		
1—materially and socially privileged	0.80 [0.47, 1.38]	0.92 [0.53, 1.59]
2—average material and social deprivation	Reference	Reference
3—materially privileged but socially deprived	1.59 [1.03, 2.45]	1.53 [0.98, 2.40]
4—materially deprived but socially privileged	1.85 [1.20, 2.85]	1.89 [1.21, 2.95]
5—materially and socially deprived	3.03 [1.99, 4.62]	2.88 [1.85, 4.49]
Surrounding environment		
Greenness within 100 m (IQR increase)	0.71 [0.60, 0.83]	0.78 [0.64, 0.91]
Building footprint within 1 km (IQR increase)	1.39 [1.15, 1.68]	–
Distance from major road (IQR increase)	0.85 [0.76, 0.95]	–
Distance from large water body (IQR increase)	1.20 [1.00, 1.46]	–

Estimates of the the OR and 95% CI are provided for seven crude models and one best-fitted adjusted model. Effects of continuous variables are shown for one IQR increase in the value, based on the distribution of the variable across all deaths. A dash indicates that the variable was not included in the best-fitted model.
95% CI, 95% confidence interval; IQR, interquartile range; OR, odds ratio.

Increasing local greenspace in neighborhoods with limited air conditioning may help to save lives during extreme hot weather.

There are several limitations to these early analyses. First, we used 6-digit postal code to identify community deaths because it takes weeks or months for the setting of death field to be populated in the vital statistics data after initial registration of the death. When we compared our method to the setting of death field for all deaths from 2013 to 2020, we found our classification of community deaths was 95% accurate. Second, some community deaths during the heat dome may not have been registered by the date of data extraction due to slowdowns caused by response to the event. Even so, we have included 434 deaths for a period during which 80 deaths were expected, meaning that 354 (82%) of the heat dome deaths were potentially due to the extreme environmental conditions.

Third, some of the data from CANUE are available for national census years only, and we used values from 2016 to the entire 2013–2021 period for the sake of consistency. There have been changes to demographics and land use in greater Vancouver over this period, so values from 2016 may be inaccurate for the earlier and later years. Future analyses should include data from the 2021 census when they become available for better characterization of circumstances during the heat dome. Fourth, it is not possible to disentangle the effects of extreme temperatures from the effects of high ground-level ozone concentrations in a period-based analysis like this. Other studies have shown that both environmental exposures contribute to increased mortality risk during similar events,[32] which was likely the case in greater Vancouver as well. However, both exposures were different facets of the same catastrophic heat dome.

Finally, we could not explicitly exclude heat dome deaths due to overdoses because it takes weeks or months for the cause of death information to become available in the vital statistics data after a death is registered. Instead, we excluded deaths in those aged <50 years. We could, however, exclude typical weather deaths due to overdose. Based on prior data, approximately 11% of the 80 community deaths in those aged 50+ expected during the heat dome would be from overdose, or 9 of the 434 total deaths included in the analyses (2%). On the other hand, 154 of the 1,517 community deaths in those 50+ in the typical weather group (10%) were due to overdose or pending causes and were excluded from the analyses. Our inability to exclude the small number of overdose deaths in the heat dome group may slightly bias results towards neighborhoods where overdoses are more common. On the other hand, including the large number of overdose deaths in the typical weather group would have caused much larger bias away from such neighborhoods when examining the heat dome effects. It is also likely that there were deaths due to suicides and drownings included in the heat dome group, though these types of accidental deaths are relatively rare compared with overdose in BC.[33,34] Although rates of overdose,[10] suicide,[35] and drowning[36] can be increased during hot weather, exposure to excessive natural heat (ICD-10 code X30) would not be identified as the primary cause of death in such cases.

Thus far, the BC Coroners Service has directly attributed 569 deaths to the heat dome across the entire province.[3] Many of these deaths will overlap with the 434 deaths (354 excess deaths) included in these analyses, although we do not know which ones. Further investigations by the Coroners Service will focus on factors such as housing conditions, indoor temperatures, presence of air conditioning, social isolation, substance dependency, and other known comorbidities. These investigations will take months to complete and analyze, but it seems likely they will find that hot residential environments overwhelmed the natural capacity for thermoregulation in susceptible people (Figure 2).[37] Our analyses indicate that these susceptibilities are strongly correlated with neighborhood deprivation, which provides an early evidence basis on which to build.

This initial investigation was conducted to support immediate shifts in provincial policy around extreme hot weather, and the evidence was used to modify the public health response during two subsequent extreme heat events in the summer of 2021. Specifically, much greater emphasis was placed on risks associated with social, economic, and built environment factors in government communications and in health authority response planning. The study results highlight the utility of readily available vital statistics and environmental data, provide evidence for targeting public health interventions, and inform ongoing research into the impacts of the heat dome. There was a strong relationship between mortality during the event and neighborhood deprivation, and clear evidence of dangerously high indoor temperatures in one illustrative home without air conditioning (Figure 2). Although data on both air conditioning and indoor temperatures are limited, we can use the available information to assume that (1) cooling is less available in materially deprived neighborhoods and (2) temperatures were very high in some homes without cooling. This allows local health authorities to identify high risk areas that can be prioritized for community engagement, cooling centers, and wellness checks. The significantly protective effect of surrounding greenness within 100 m indicates that urban heat islands were also associated with increased risk and suggests that initiatives to increase greenspace must continue.[38] Much more research is needed, but there is clear value in these early analyses for generating evidence to drive immediate shifts in policy and for guiding future work.

Acknowledgments

The Material and Social Deprivation Indices (MSDI), Normalized Difference Vegetation Index (NDVI), building density, road distance, and water distance metrics, all indexed to DMTI Spatial Inc. 6-digit postal codes, were provided by CANUE (Canadian Urban Environmental Health Research Consortium).

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