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# Estimating municipal life expectancy and health-adjusted life expectancy in Canada, 2019 and 2020

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## ABSTRACT


### Background

Data measuring life expectancy (LE) and health-adjusted life expectancy (HALE) in Canada are available for large geographical areas, such as provinces, territories, and health regions. However, to date, no study has analyzed LE and HALE at the municipal level.

### Data and methods

Death and population counts from January 1, 2019, to December 31, 2020, were retrieved for 1,227 census subdivisions (CSDs) in Canada. CSDs are municipalities or areas treated as municipal equivalents by provincial and territorial governments. Functional health status was operationalized via the Health Utilities Index Mark 3 (HUI3) and obtained from the 2019 and 2020 Canadian Community Health Survey. CSD mortality rates and HUI3 scores for sex and age groups were estimated via multilevel regression models and poststratification. LE and HALE were calculated using life table methods and compared with previously published data for a subset of CSDs. The variability of LE and HALE was described using population, income, and educational characteristics.

### Results

The median CSD had estimates of LE at birth of 84.1 years for females and 79.6 years for males. The median CSD had estimates of HALE at birth of 70.8 years for females and 68.3 years for males. For both measures, the gaps between CSDs at the 95th and 5th percentiles of LE were approximately 13 years for females and 14 years for males. The differences between the model-based LE estimates and published data were typically less than one year. LE and HALE at birth were positively correlated with population size and the percentage of individuals aged 25 to 64 with a postsecondary education.

### Interpretation

This study develops, validates, and describes the first set of LE and HALE estimates for municipalities in Canada. Municipal-level health indicators are important for research and policy focused on the health of local populations.



### Keywords

Life expectancy, health-adjusted life expectancy, municipalities, multilevel modelling


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## *What is already known on this subject?*

- Life expectancy (LE) and health-adjusted life expectancy (HALE) are common indicators of population health.
- LE data in Canada are available for provinces, territories, and health regions, but not for smaller geographical areas.
- Sparse administrative and survey data in smaller areas make local health indicators challenging to estimate.

## *What does this study add?*

- This study develops the first set of LE and HALE estimates for municipalities in Canada.
- The gap in LE between census subdivisions at the 5th and 95th percentiles is about 1.5 years greater for males than females.
- LE at birth and HALE at birth are positively correlated with population size and educational attainment.
- LE and HALE estimates are consistent with previously published data for a subset of municipalities.

Life expectancy (LE) measures the average number of remaining years of life, and health-adjusted life expectancy (HALE) measures the average number of remaining years of life in good health.[1,2] LE and HALE are indicators of population health monitored by many international, national, and subnational public health agencies. In Canada, data measuring LE and HALE are most commonly available for large geographic areas. Statistics Canada publishes national-, provincial-, territorial-, and health region-level estimates of LE, as well as national-level estimates of HALE.[3,4] Similarly, past research has estimated LE, HALE, or related measures (e.g., disability-free LE) for provinces[5,6] and health regions,[7,8] as well as for aggregations of cities and regions that have similar social, economic, and built environment characteristics.[1,5,9-11]

Motivated by research and policy interest in measuring the health of local populations, there is a growing interest in the production of health indicators for subregional geographies in Canada and elsewhere.[1,12-16] However, no study to date has analyzed LE or HALE at the municipal level in Canada. One possible explanation for the lack of research analyzing LE and HALE at smaller geographical levels is data sparsity. For LE, small population and death counts in age–sex strata may result in mortality rates that do not reflect the true underlying mortality risks.[1,14] For HALE, the national surveys that typically capture functional health status, such as activities of daily living, pain, and cognition, may have limited coverage.[1,17] Understanding LE and HALE at the municipal level is important for two reasons. First, municipal contexts may influence LE and HALE through, for example, housing;[18-20] land use and green space;[21-23] local social, economic, and demographic characteristics;[24] and the initiatives of local health care and public health agencies.[25,26] Second, municipal-level LE and HALE data are relevant for governments, public health agencies, and researchers interested in public health planning and understanding how health, well-being, and quality of life vary across Canada for smaller geographical areas.

This study develops, validates, and describes the first set of LE and HALE estimates for a large set of municipalities in Canada. The first objective of this study was to model age- and sex-specific mortality rates, functional health status scores, LE at birth, and HALE at birth for a large set of census subdivisions (CSDs) in 2019 and 2020. To address issues related to sparse administrative and survey data in small geographic areas, this study applies multilevel regression models and poststratification methods that have been shown to provide reliable estimates of population- and small area-level quantities from health surveys.[16,17,27-31] The second objective of this study was to validate this set of LE and HALE estimates against previously published data. The third objective was to describe how LE, HALE, and the proportion of life years in full health at the municipal level were correlated with local sociodemographic characteristics.

## Study regions, data, and methods

The geographic unit of analysis for this study was the CSD. CSDs are municipalities or areas treated as municipal equivalents by provincial and territorial governments (e.g., cities, settlements, reserves, and townships).[32] In total, 5,161 CSDs had population data in 2019 and 2020, as provided by Statistics Canada. Of these CSDs, 999 were excluded for having fewer than 5,000 person-years at risk,[33] and an additional 2,815 were excluded because of missing population data, zero deaths across all age groups, or zero deaths in the terminal age group. In the 2019 and 2020 Canadian Community Health Survey (CCHS), 1,227 of the remaining 1,347 CSDs were represented by at least one respondent with valid functional health status values. The final set of 1,227 CSDs selected for analysis accounted for approximately 92% of the national population (69.6 million individuals combined in 2019 and 2020) and 93% of all deaths. The mean population size of the CSDs in 2019 and 2020 (combined) was 56,714, with a range from 545 in Fillmore, Saskatchewan, to 5.8 million in Toronto, Ontario. Of the CSDs excluded from the analysis, 25% were classified as Indian reserves, 14% as municipalities, 12% as villages, and 11% as towns.

## Mortality and population data

Mortality data for the 1,227 CSDs were retrieved from the Canadian Vital Statistics - Death database from January 1, 2019, to December 31, 2020, inclusively. This two-year period was chosen to align with the most recently available CCHS data containing the measures of functional health status required to calculate HALE. Two-year mortality counts were aggregated by sex, age group, and CSD. Following the abridged life tables published by Statistics Canada,[34] 20 age groups were analyzed: 0 years, 1 to 4 years, 5 to 10 years, 11 to 14 years, 15 to 19 years, 20 to 24 years, 25 to 29 years, 30 to 34 years, 35 to 39 years, 40 to 44 years, 45 to 49 years, 50 to 54 years, 55 to 59 years, 60 to 64 years, 65 to 69 years, 70 to 74 years, 75 to 79 years, 80 to 84 years, 85 to 89 years, and 90 years and older. Two-year population counts by sex, age group, and CSD were obtained from Statistics Canada. See Appendix A for descriptive statistics of the mortality rates. In general, the overall sex- and age group-specific mortality rates were similar for the CSDs included in this study and those excluded from it.

## Health Utilities Index Mark 3 data

Functional health status was measured using the Health Utilities Index Mark 3 (HUI3), as collected on the 2019 and 2020 CCHS. The CCHS is an annual cross-sectional survey of approximately 65,000 respondents that collects person-level information related to socioeconomic status, health status and determinants, and health care use.[35] The CCHS target population is people aged 12 years and older living in the 10 provinces and three territorial capitals. The CCHS excludes people living on reserves and other Indigenous settlements, full-time members of the Canadian Forces, institutionalized populations (e.g., in correctional facilities, long-term care centres, and hospitals), and children aged 12 to 17 living in foster care. The CCHS is the only national-level survey measuring HUI3.

Previously used to calculate HALE,[15,36] HUI3 is a classification system that measures eight dimensions of health status and health-related quality of life: vision, hearing, speech, ambulation, dexterity, emotion, cognition, and pain.[37] A weighted scoring function was applied to combine the eight dimensions into a single HUI3 score representing the overall health state.[37] Person-level HUI3 scores for all CCHS respondents (i.e., those aged 12 years and older) ranged from -0.36 to 1, where a value less than 0 represents a health status worse than death, a value of 0 represents death, and a value of 1 represents no functional health issues.[37] In the 2019 and 2020 CCHS, 90,220 of the 95,523 respondents in the 1,227 CSDs (94%) had complete HUI3 data and were retained for analysis. See Appendix B for descriptive statistics of the HUI3 scores.

## Multilevel modelling of census subdivision mortality rates

A multilevel binomial regression model was used to estimate sex-, age group-, and CSD-specific mortality rates based on the observed death and population counts. Specifically, the mortality rates for each sex were modelled on the logit scale as a function of an overall intercept and random effect terms for age groups, CSDs, the interaction between age groups and CSDs, and health regions. The random effect term representing the modelled mortality rates for the 0-year age group was set to 0 for model identifiability. The age group random effect terms were modelled separately for females and males,[14] whereas the CSD random effect terms were allowed to be correlated between the two sexes. See Appendix C for additional details.

## Multilevel modelling and poststratification weighting of Health Utilities Index Mark 3 scores

Sex-, age group-, and CSD-specific HUI3 scores were estimated using multilevel regression and poststratification. First, person-level HUI3 scores were modelled using a multilevel regression model that included a covariate representing male participants and random effect terms for five age groups (12 to 24 years, 25 to 44 years, 45 to 64 years, 65 to 79 years, and 80 years and older[2]), the interactions between the two sexes and five age groups, and four person-level sociodemographic characteristics available on the 2019 and 2020 CCHS and similarly defined in the 2016 Census: educational attainment (less than secondary school, secondary school, more than secondary school, or not stated), home ownership (owner, renter, or other), immigrant status (immigrated five years ago or less, immigrated more than five years ago, born in Canada, or non-response), and marital status (married or common-law; widowed, separated, or divorced; single; or don't know, refusal, or not stated).[35] Non-response, not stated, and other categories were included in the model (e.g., the random effect terms for educational attainment had four categories). Random effect terms were also included for the CSD, health region, and province or territory of residence. See Appendix D for additional details.

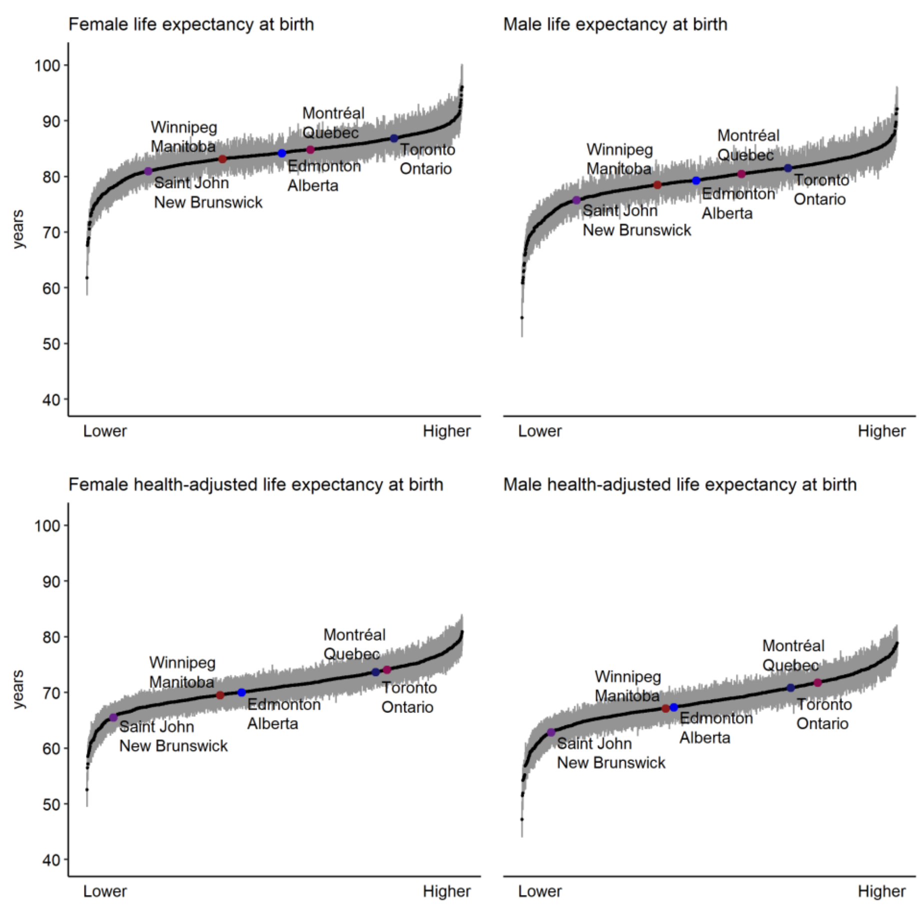
Second, based on the results of the multilevel regression model, average HUI3 scores were predicted for 662,580 poststratification cells defined by the cross-classification of sex, age group, educational attainment, home ownership, immigrant status, marital status, and CSD. Non-response, not stated, and other categories were not included when creating the poststratification cells, because these responses are not reflected in the census and therefore do not have a corresponding weight. Poststratification weights were defined as the proportion of individuals with the same characteristics per sex, age group, and CSD in the 2016 Census. These weights were then applied to the HUI3 scores in the corresponding 54 sex–age group–CSD strata (i.e., 270 strata per sex in each CSD and 540 strata per CSD) to produce overall weighted mean HUI3 scores for each sex and age group at the CSD level.

### Model fitting and calculating life expectancy and health-adjusted life expectancy

The models were fit in the Bayesian statistical framework using the *brms* package (v. 2.21.0)[38] in the R statistical software (v.4.1).[39] Model code is available upon request. The models were fit using two chains, and each chain was run for 2,000 iterations. Model convergence was confirmed via visual inspections of parameter trace plots and R-hat statistics close to 1. The first 1,000 iterations of each chain were discarded as burn-in, and the remaining 1,000 iterations were retained for posterior inference. The results presented below summarize the 2,000 iterations of the posterior distributions via the mean and 95% credible interval (CI). The 95% CI is the interval that contains the true value of a parameter with 95% probability. See appendices E and F for model results.

Life table methods were applied to the modelled mortality rates to calculate death probabilities and LE.[40,41] To calculate HALE, the LE and HUI3 estimates were aligned based on sex, age group, and CSD. Individuals younger than 10 years were assumed to have a perfect health status and assigned HUI3 scores of 1.[1] The age group representing individuals aged 10 to 14 years in the abridged life table was assigned the HUI3 score for the 12-to-24-years age group. HALE was calculated using a modified version of the Sullivan method,[42] where the number of life years lived (calculated as part of LE) was weighted by the modelled HUI3 score for the same sex, age group, and CSD. HALE was then calculated by dividing the sum of life years beyond a given age group by the number of survivors in the same age group.[43] The proportion of life years in full health was calculated as the quotient of HALE and LE.

**Figure 1**
**Ranked life expectancy at birth (top) and health-adjusted life expectancy at birth (bottom) for females (left) and males (right) in 1,227 census subdivisions in Canada**




**Notes:** The 95% uncertainty intervals are shown as grey vertical lines. Selected census subdivisions are highlighted.

**Sources:** Statistics Canada, Canadian Vital Statistics - Death database, population data, 2019 and 2020 Canadian Community Health Survey.

### Validation of life expectancy and health-adjusted life expectancy estimates

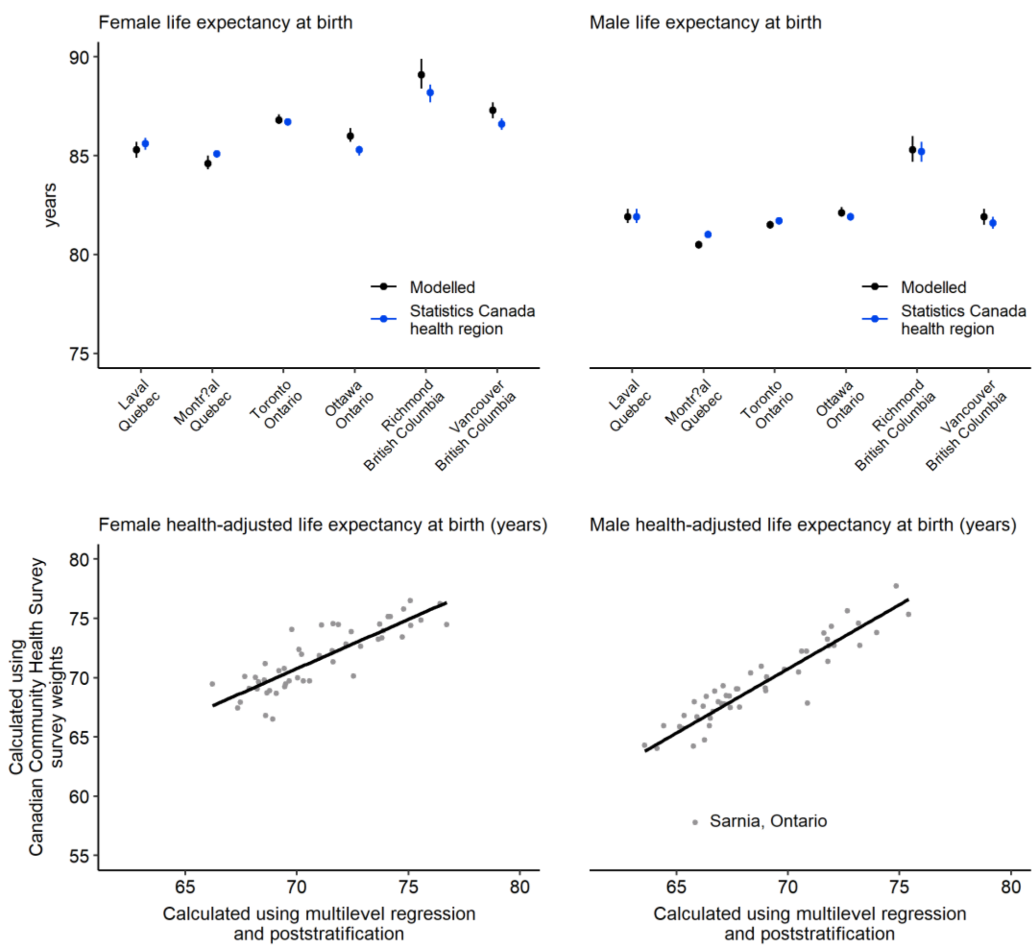
The LE and HALE estimates produced by the methods described above were validated in two ways. First, LE at birth was compared with the most recent data published by Statistics Canada (2015 to 2017) for the six health regions and CSDs with similar geographical boundaries (see Appendix G). The similarity of CSD and health region boundaries was determined by visual inspection. Second, the HALE at birth estimates were compared with HALE at birth calculated using CCHS survey weights to derive sex-, age group-, and CSD-specific HUI3 scores for 49 CSDs (see Appendix H). These 49 CSDs had at least 10 respondents in each age group for both sexes, in accordance with the CCHS data releasability guidelines.[44] Note that the subset of CSDs used for validation may not be representative of all CSDs in this study or in Canada.

### Describing census subdivision life expectancy, health-adjusted life expectancy, and life years in full health

Four characteristics were chosen to explore the between-CSD variability of LE at birth, HALE at birth, and the proportion of life years at birth in full health: population size, population density, the average after-tax income of economic families, and the percentage of individuals aged 25 to 64 with a postsecondary degree. Population size and population density describe the urban–rural gradient of LE often explored in past research.[11,45] The average after-tax income of economic families and the percentage of individuals aged 25 to 64 with a

**Figure 2**

**Comparisons of life expectancy at birth for six census subdivisions and health regions with similar geographies (top) and comparisons of health-adjusted life expectancy at birth for 49 census subdivisions calculated using the 2019 and 2020 Canadian Community Health Survey survey weights (bottom)**




**Sources:** Statistics Canada, Canadian Vital Statistics - Death database, population data, 2019 and 2020 Canadian Community Health Survey, census data, and Table 13-10-0389-01.

postsecondary degree are two socioeconomic characteristics that have been shown to be positively correlated with both LE and HALE.[2,5,46] The relationships between the four CSD characteristics and LE, HALE, and the proportion of life years in full health were quantified via the Kendall τ rank correlation coefficient. Compared with the CSDs included in the analysis, the excluded CSDs generally had smaller population counts, population densities, average after-tax incomes, and postsecondary degree attainment rates.

## Results

Figure 1 ranks the 1,227 CSDs based on LE at birth and HALE at birth. Across all CSDs, the median LE at birth was 84.1 years (95% CI: 83.9 to 84.2) for females and 79.6 years (95% CI: 79.5 to 79.8) for males. These estimates align with national-level data published by Statistics Canada for 2019 and 2020.[3] The CSDs most likely to be representative of the median LE at birth were the cities of Edmonton, Alberta, and Hamilton, Ontario, for females and the cities of Gatineau, Quebec, and Kitchener, Ontario, for males. Female LE was greater than male LE in all CSDs, with a mean difference of 4.5 years (95% CI: 3.0 to 5.9). The LE gap between CSDs at the 95th and 5th percentiles was approximately 12.5 years (95% CI: 12.0 to 13.1) for females and 13.9 years (95% CI: 13.4 to 14.5) for males. The LE gap between CSDs at the 75th and 25th percentiles was approximately 4.3 years (95% CI: 4.1 to 4.5) for females and 4.8 years (95% CI: 4.6 to 5.1) for males.

Focusing on HALE, the median estimates were 70.8 years (95% CI: 70.6 to 71.1) for females and 68.3 years (95% CI: 68.1 to 68.6) for males across this set of CSDs. Statistics Canada reported a HALE of 69.7 years from 2015 to 2017 for females and males combined at the national level.[4] For females, the CSDs most likely to be representative of the median were the cities of Maple Ridge and Abbotsford, British Columbia. For males, the CSDs most likely to be representative of the median were Norfolk County and the municipality of Lakeshore, Ontario. Like LE, female HALE was greater than male HALE in all CSDs, with an average difference of approximately 2.5 years (95% CI: 1.3 to 3.8). The HALE gap between CSDs at the 5th and 95th percentiles was approximately 13.0 years (95% CI: 12.4 to 13.5) for females and 13.9 years (95% CI: 13.4 to 14.5) for males. The HALE gap between CSDs at the 25th and 75th percentiles was approximately 5.2 years (95% CI: 4.9 to 5.5) for females and 5.6 years (95% CI: 5.3 to 5.9) for males. In general, CSDs with higher LE at birth also had higher HALE at birth (Kendall τ rank correlation coefficients were 0.64 for females and 0.70 for males).

### Validation of census subdivision life expectancy and health-adjusted life expectancy estimates

Figure 2 compares a subset of CSD-level estimates of LE and HALE at birth from this study with LE data previously published for health regions and with HALE estimates calculated using 2019 and 2020 CCHS survey weights. For LE at birth, the absolute mean difference was 0.28 years for females and 0.01 years for males. The two sets of female and male LE at birth estimates were within 1 year and 0.5 years in all six CSDs, respectively. A notable difference in LE at birth was observed for females in Ottawa; the City of Ottawa Health Unit had an LE of 85.3 years (95% CI: 85.0 to 85.5), compared with 86.0 years (95% CI: 85.7 to 86.4) in the CSD. The absolute mean differences in LE at age 65 (not shown) were 0.5 years for females and 0.4 years for males, and the two sets of estimates were within 1 year for all six CSDs.

For HALE at birth, the two sets of estimates were positively correlated (Pearson's $r$ = 0.85 for females and 0.89 for males) and had absolute mean differences of 1.2 years for females and 1.3 years for males. The largest difference in HALE at birth was for males in Sarnia, Ontario, with an estimated 65.8 years in this study, compared with 57.8 years based on the CCHS survey weights. The two sets of female and male HALE at birth estimates were within 4.3 years and 3.0 years, respectively, for this set of 49 CSDs (excluding Sarnia, Ontario). The absolute mean difference between the two sets of HALE estimates at age 65 (not shown) was 0.7 years for females and males, and the two sets of estimates were within 3.5 years for females and 2.3 years for males for all 49 CSDs.

**Table 1**
**Kendall τ rank correlation coefficients between life expectancy at birth, health-adjusted life expectancy at birth, and proportion of life years in full health at birth and four census subdivision characteristics**

| | Life expectancy at birth | | Health-adjusted life expectancy at birth | | Proportion of life years in full health | |
|---|---|---|---|---|---|---|
| | Female | Male | Female | Male | Female | Male |
| Population size | 0.12 * | 0.12 * | 0.10 * | 0.11 * | -0.02 | 0.00 |
| Population density (number of people per km$^2$) | -0.04 | -0.04 * | 0.01 | 0.01 | 0.06 * | 0.10 * |
| Average after-tax income in economic families ($) | 0.11 * | 0.11 * | 0.03 | 0.04 | -0.07 * | -0.07 * |
| Individuals aged 25 to 64 with a postsecondary education (%) | 0.24 * | 0.27 * | 0.35 * | 0.36 * | 0.32 * | 0.34 * |

* significantly different from 0 ($p < 0.05$)

**Sources:** Statistics Canada, Canadian Vital Statistics - Death database, population data, 2019 and 2020 Canadian Community Health Survey, and census data.

**Life expectancy, health-adjusted life expectancy, and census subdivision characteristics**

Table 1 shows the Kendall τ rank correlation coefficients between LE, HALE, and the proportion of life years in full health at birth and the four CSD characteristics. All three LE metrics for females and males were positively correlated with the proportion of individuals aged 25 to 64 years with postsecondary education. LE and HALE were positively correlated with population size and the average after-tax income of economic families, but these were negatively correlated with the proportion of life years in full health. Population density exhibited the weakest correlations with LE and HALE.

# Discussion

This study has developed, validated, and described the first set of LE and HALE estimates at the municipal level in Canada. Despite LE and HALE being common health indicators tracked by many international, national, and subnational agencies, no past research has produced LE and HALE for Canadian cities, towns, or equivalent administrative areas. Following past research in international contexts analyzing health indicators for small areas and sparse data contexts,[16,17,30,31] this study applies a combination of multilevel models and poststratification methods to produce stable sex-, age group- and CSD-specific mortality rates, HUI3 scores, and estimates of LE and HALE.

To explore the degree to which the LE and HALE estimates produced in this study compared to previously published data, LE at birth was validated against 2015-to-2017 data for six health regions with similar geographies, and HALE at birth was validated against HALE at birth calculated using CCHS survey weights. Overall, the LE and HALE estimates derived from the modelled mortality rates and HUI3 scores were similar to the validation data. The two sets of HALE estimates, however, exhibited notably larger differences than the LE estimates. This is likely attributable to the uncertainty arising from the use of national-level survey data for small-area estimation. Illustrative of this was an eight-year difference between the model- and weight-based HALE at birth estimates for males in Sarnia, Ontario. This discrepancy may be explained by HUI3 scores for males aged 25 to 44; the CCHS weights suggest a CSD-level score of 0.53 for this stratum, compared with 0.85 using the multilevel regression and poststratification methods. For reference, the average HUI3 score for males aged 25 to 44 in the subset of 49 CSDs used for the validation of HALE at birth was 0.88 using the CCHS survey weights and multilevel regression and poststratification.

The CSD-level estimates of LE and HALE produced in this study may be relevant to government, public health agencies, and researchers interested in understanding health, well-being, and quality of life in Canada. This study provides only a brief exploration of the ways in which these CSD-level data can advance knowledge of how and why LE and HALE vary across these local geographies. For example, this study shows that the between-CSD gaps in LE were greater for males than females; comparing the 95th and 5th percentile CSDs and 75th and 25th percentile CSDs, the study found that the gaps for male LE were 1.3 years (95% CI: 0.7 to 1.9) and 0.6 years (95% CI: 0.3 to 0.8) greater, respectively, than the gaps for female LE. Similar findings have been observed for regional or subregional geographies in England;[14] the United States;[47] and Quebec, Canada.[5] They may point to characteristics associated only with male mortality (e.g., the employment opportunities in CSDs and corresponding occupational risks).[48] Similarly, the correlation analyses suggest that postsecondary education exhibits the strongest positive correlations with LE, HALE, and the proportion of life years in full health at birth, and that these correlations were greater for males than females. This finding aligns with past studies illustrating the importance of education and associated socioeconomic conditions in explaining the variability of these three health indicators in Canadian[2] and international contexts.[46]

**Strengths, limitations, and future research**

Strengths of this study were the use of detailed and high-quality administrative and survey data, a validated measure of functional health status, and statistical modelling methods that have been shown to produce reliable estimates of population- and small area-level quantities from national health surveys. While there were few data sources for validation of the CSD-level estimates, an additional strength of this study is the comparison of the LE estimates with previously published data and of the HALE estimates with the results of an alternative analytical approach.

The first limitation of this study is that the sampling frame for the 2019 and 2020 CCHS excludes institutionalized populations, and so the HALE estimates developed in this study may be higher than the true values, particularly in CSDs with large hospitals or correctional facilities.[36] Future research could consider analyzing HALE for subregional geographies using data from both the CCHS and institutionalized populations. Second, this study does not provide estimates of LE and HALE for all CSDs in Canada because of small population sizes and limited CCHS coverage in 2019 and 2020. Aggregating additional years would allow for broader coverage of CSDs but would challenge temporal inference and obscure time trends. Third, this study does not consider within-age group variability of the HUI3 scores or characteristics associated with HUI3 scores not captured in the census, such as health behaviours.[36] Future research could look to develop modelling approaches that incorporate alternative data sources or the correlation structures between more precise categories.[49,50]

Future research may also explore the associations between CSD-level LE, HALE, and the proportion of life years in full health and a variety of sociodemographic, economic, and built environment characteristics to better understand how and why these measures vary across Canada. To further advance the use of national health surveys to measure local population health, it may be useful to investigate population thresholds for which LE and HALE can be reliably estimated, as well as methodological comparisons between the approach developed in this study and estimates produced using area-level methods (e.g., Fay–Herriot models) previously applied to create small-area health indicators using CCHS data.[51,52] Finally, analyses of the spatial-temporal patterns of overall and sex-specific LE, HALE, and other health indicators at the CSD level could help to understand how the health of local populations has evolved over time and the impacts of location- and time-specific sociodemographic characteristics, policies, and public health emergencies (e.g., the COVID-19 pandemic or drug overdose crises).

**Appendix A**

**Descriptive statistics for mortality rates (per 1,000) in 1,227 census subdivisions and percentage of census subdivisions with zero death counts in 2019 and 2020**

| | Female | | | Male | | |
|---|---|---|---|---|---|---|
| | Mortality rate (per 1,000) | | CSDs with zero death count | Mortality rate (per 1,000) | | CSDs with zero death count |
| Age group (years) | mean | standard deviation | percent | mean | standard deviation | percent |
| 0 | 4.84 | 20.13 | 71.56 | 5.44 | 15.26 | 66.91 |
| 1 to 4 | 0.16 | 1.11 | 91.85 | 0.19 | 1.16 | 90.55 |
| 5 to 9 | 0.06 | 0.68 | 93.73 | 0.09 | 0.60 | 92.50 |
| 10 to 14 | 0.10 | 0.72 | 93.00 | 0.15 | 0.90 | 90.22 |
| 15 to 19 | 0.34 | 1.47 | 83.13 | 0.61 | 1.81 | 74.74 |
| 20 to 24 | 0.50 | 2.06 | 79.06 | 1.08 | 2.81 | 63.49 |
| 25 to 29 | 0.56 | 2.43 | 76.12 | 1.68 | 3.97 | 57.38 |
| 30 to 34 | 0.63 | 1.95 | 72.21 | 1.51 | 3.35 | 56.64 |
| 35 to 39 | 0.96 | 2.42 | 65.28 | 1.77 | 3.57 | 52.89 |
| 40 to 44 | 1.12 | 2.78 | 61.45 | 2.22 | 3.99 | 47.60 |
| 45 to 49 | 1.77 | 3.07 | 50.53 | 2.99 | 4.90 | 38.79 |
| 50 to 54 | 2.93 | 4.63 | 36.02 | 4.36 | 5.33 | 26.08 |
| 55 to 59 | 4.32 | 4.52 | 20.70 | 6.77 | 6.63 | 12.14 |
| 60 to 64 | 6.68 | 6.05 | 13.20 | 10.45 | 8.96 | 6.76 |
| 65 to 69 | 10.13 | 8.38 | 8.07 | 16.24 | 14.17 | 3.50 |
| 70 to 74 | 16.43 | 12.22 | 5.46 | 24.68 | 15.92 | 2.77 |
| 75 to 79 | 27.85 | 18.25 | 3.75 | 41.11 | 35.35 | 2.69 |
| 80 to 84 | 51.40 | 44.08 | 3.91 | 71.88 | 54.40 | 2.12 |
| 85 to 89 | 95.47 | 75.65 | 4.40 | 134.00 | 94.91 | 2.04 |
| 90 and older | 234.92 | 157.64 | 0.00 | 277.56 | 187.57 | 0.00 |

**Note:** CSD = census subdivision.

**Sources:** Statistics Canada, Canadian Vital Statistics - Death database, and population data, 2019 and 2020.

**Appendix B**

**Descriptive statistics for Health Utilities Index Mark 3 scores in 1,227 census subdivisions and percentage of census subdivisions with no respondents with Health Utilities Index Mark 3 data in 2019 and 2020 Canadian Community Health Survey**

| | Female | | | Male | | |
|---|---|---|---|---|---|---|
| | HUI3 score | | CSDs with no respondents | HUI3 score | | CSDs with no respondents |
| Age group (years) | mean | standard deviation | percent | mean | standard deviation | percent |
| 12 to 24 | 0.86 | 0.20 | 67.73 | 0.88 | 0.17 | 67.56 |
| 25 to 64 | 0.87 | 0.19 | 73.26 | 0.89 | 0.18 | 68.38 |
| 45 to 64 | 0.82 | 0.23 | 79.14 | 0.84 | 0.22 | 77.26 |
| 65 to 79 | 0.81 | 0.23 | 84.52 | 0.83 | 0.22 | 62.56 |
| 80 and older | 0.70 | 0.28 | 61.94 | 0.73 | 0.28 | 53.38 |

**Notes:** HUI3 = Health Utilities Index Mark 3; CSD = census subdivision.

**Source:** Statistics Canada, 2019 and 2020 Canadian Community Health Survey.

## Appendix C

### Additional details for multilevel modelling of mortality rates

The death counts for sex $i$ (= male, female), age group $j$ (= 1, …, 20), and census subdivision $k$ (= 1, …, 1,227) were assumed to follow a binomial likelihood conditional on unknown mortality rates $p_{ijk}$ and known population counts $n_{ijk}$: $y_{ijk} \sim Binomial\left(p_{ijk}, n_{ijk}\right)$. As described in Model 1, the sex-specific mortality rates were modelled (on the logit scale) as a function of an overall intercept ($\alpha_i$) and four sets of random effect terms that capture the variation in mortality rates between age groups ($\lambda_{ij}$), census subdivisions ($\gamma_{ik}$), health regions ($\theta_{ir[k]}$ for census subdivision $k$ nested in health region $r$ = 1, …, 99), and the interaction between age groups and census subdivisions ($\xi_{ijk}$). Following past research observing different age-specific mortality patterns for females and males[1], the $\lambda_{ij}$'s were modelled separately whereas the $\gamma_{ik}$'s were allowed to be correlated between females and males. The $\alpha_i$'s were assigned normal prior distributions with means of -5 and standard deviations of 3. This corresponds to a prior assumption that the overall average mortality rates (across all age groups and census subdivisions) were approximately 0.007 per 100. The random effect terms $\lambda_{ij}$, $\gamma_{ik}$, $\theta_{ir[k]}$, and $\xi_{ijk}$ were assigned sex-specific normal prior distributions with means of 0 and unknown standard deviations $\sigma_{\lambda_i}$, $\sigma_{\gamma_i}$, $\sigma_{\theta_i}$, and $\sigma_{\xi_i}$, respectively. The standard deviations were assigned positive half-normal prior distributions with means of 0 and standard deviations of 1[2]

$$logit\left(p_{ijk}\right) = \alpha_i + \lambda_{ij} + \gamma_{ik} + \theta_{ir[k]} + \xi_{ijk} \qquad (1)$$

## Appendix D

### Additional details for multilevel modelling of Health Utilities Index Mark 3 scores

The Health Utilities Index Mark 3 score for person $s$ was assumed to follow a normal distribution with mean $\mu_s$ and overall standard deviation $\sigma$. The $\mu_s$'s were modelled as a function of an overall intercept ($\alpha$); a covariate representing male respondents ($\beta$); and random effect terms for age groups ($\lambda_a$), the interaction between sex and age group ($\kappa_{xa}$), educational attainment ($\xi_e$), marital status ($\nu_m$), homeownership ($\omega_h$), immigrant status ($\upsilon_i$), census subdivision ($\gamma_k$), health region ($\theta_r$), and province or territory of residence ($\eta_p$) (Equation 2). The coefficient was assigned a normal prior distribution with a mean of 0 and a standard deviation of 1. Each of the random effect terms was assigned a normal prior distribution with a mean of 0 and an unknown standard deviation: $\sigma_\lambda$ for age groups, $\sigma_\kappa$ for the intersection of sex and age group, $\sigma_\xi$ for educational attainment, $\sigma_\nu$ for marital status, $\sigma_\omega$ for homeownership, $\sigma_\upsilon$ for immigrant status, $\sigma_\gamma$ for census subdivisions, $\sigma_\theta$ for health regions, and $\sigma_\eta$ for the provinces and territories. The standard deviations were assigned positive half-normal prior distributions with means of 0 and standard deviations of 1[2]

$$\mu_s = \alpha + \beta \cdot male_s + \lambda_a + \kappa_{ax} + \xi_e + \nu_m + \omega_h + \upsilon_i + \gamma_k + \theta_r + \eta_p \qquad (2)$$

**Appendix E**
**Results from the mortality rate model described in Appendix C**

| | Female | | | | Male | | | |
|---|---|---|---|---|---|---|---|---|
| | posterior mean | 2.5 percentile | 97.5 percentile | R-hat | posterior mean | 2.5 percentile | 97.5 percentile | R-hat |
| Intercept (= $\exp(\alpha_i) / (1 + \exp(\alpha_i))$) | 0.004 | 0.003 | 0.004 | 1.00 | 0.005 | 0.004 | 0.005 | 1.00 |
| Standard deviation of random effect terms | | | | | | | | |
| Age group ($\sigma_{\lambda i}$) | 2.22 | 1.74 | 2.88 | 1.01 | 2.19 | 1.66 | 2.87 | 1.00 |
| Census subdivision ($\sigma_{\gamma i}$) | 0.37 | 0.36 | 0.39 | 1.00 | 0.38 | 0.36 | 0.40 | 1.00 |
| Age group–census subdivision ($\sigma_{\xi i}$) | 0.21 | 0.20 | 0.22 | 1.01 | 0.19 | 0.18 | 0.19 | 1.00 |
| Health region ($\sigma_{\theta i}$) | 0.01 | 0.00 | 0.04 | 1.00 | 0.04 | 0.03 | 0.05 | 1.01 |
| Correlation between $\sigma_{\gamma female}$ and $\sigma_{\gamma male}$ | 0.99 | 0.99 | 1.00 | 1.00 | 0.99 | 0.99 | 1.00 | 1.00 |

**Sources:** Statistics Canada, Canadian Vital Statistics - Death database and population data.

**Appendix F**
**Results from the Health Utilities Index Mark 3 model described in Appendix D**

| Model term | Posterior mean | 2.5 percentile | 97.5 percentile | R-hat |
|---|---|---|---|---|
| Intercept ($\alpha$) | 0.78 | 0.62 | 0.96 | 1.00 |
| Coefficient for male respondents ($\beta$) | 0.01 | 0.00 | 0.02 | 1.01 |
| Overall standard deviation ($\sigma$) | 0.22 | 0.21 | 0.22 | 1.00 |
| Standard deviations of random effect terms | | | | |
| Age group ($\sigma_{\lambda}$) | 0.09 | 0.04 | 0.24 | 1.00 |
| Sex–age group ($\sigma_{\kappa}$) | 0.01 | 0.01 | 0.02 | 1.00 |
| Educational attainment ($\sigma_{\xi}$) | 0.04 | 0.01 | 0.15 | 1.00 |
| Marital status ($\sigma_{\nu}$) | 0.03 | 0.01 | 0.11 | 1.00 |
| Homeownership ($\sigma_{\omega}$) | 0.08 | 0.02 | 0.27 | 1.00 |
| Immigrant status ($\sigma_{\upsilon}$) | 0.04 | 0.01 | 0.15 | 1.00 |
| Census subdivision ($\sigma_{\gamma}$) | 0.01 | 0.00 | 0.01 | 1.00 |
| Health region ($\sigma_{\theta}$) | 0.01 | 0.01 | 0.01 | 1.00 |
| Province ($\sigma_{\eta}$) | 0.02 | 0.01 | 0.04 | 1.00 |

**Source:** Statistics Canada, 2019 and 2020 Canadian Community Health Survey.

**Appendix G**
**Six census subdivisions and health regions with similar geographical boundaries**

| Census subdivision | Health region |
|---|---|
| Toronto, Ontario | City of Toronto Health Unit |
| Hamilton, Ontario | City of Hamilton Health Unit |
| Ottawa, Ontario | City of Ottawa Health Unit |
| Richmond, British Columbia | Richmond Health Service Delivery Area |
| Vancouver, British Columbia | Vancouver Health Service Delivery Area |
| Laval, Quebec | Région de Laval |
| Montréal, Quebec | Région de Montréal |

**Appendix H**

**Forty-nine census subdivisions that met releasability guidelines**

| | |
|---|---|
| Abbotsford, British Columbia | Brandon, Manitoba |
| Burlington, Ontario | Calgary, Alberta |
| Cape Breton, Nova Scotia | Charlottetown, Prince Edward Island |
| Chatham-Kent, Ontario | Edmonton, Alberta |
| Fredericton, New Brunswick | Gatineau, Quebec |
| Greater Sudbury, Ontario | Halifax, Nova Scotia |
| Hamilton, Ontario | Kamloops, British Columbia |
| Kelowna, British Columbia | Kingston, Ontario |
| Laval, Quebec | Lethbridge, Alberta |
| London, Ontario | Markham, Ontario |
| Medicine Hat, Alberta | Mississauga, Ontario |
| Moncton, New Brunswick | Montréal, Quebec |
| Moose Jaw, Saskatchewan | Nanaimo, British Columbia |
| Norfolk County, Ontario | Oakville, Ontario |
| Ottawa, Ontario | Peterborough, Ontario |
| Prince George, British Columbia | Québec, Quebec |
| Red Deer, Alberta | Regina, Saskatchewan |
| Richmond, British Columbia | Saguenay, Quebec |
| Sarnia, Ontario | Saskatoon, Saskatchewan |
| Sherbrooke, Quebec | St. Catharines, Ontario |
| St. John’s, Newfoundland and Labrador | Strathcona County, Alberta |
| Surrey, British Columbia | Thunder Bay, Ontario |
| Toronto, Ontario | Trois-Rivières, Quebec |
| Vancouver, British Columbia | Windsor, Ontario |
| Winnipeg, Manitoba | |

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