QUANTITATIVE RESEARCH

Lifetime excess cancer risk due to carcinogens in food and beverages: Urban versus rural differences in Canada

Roslyn Cheasley, MSc, C. Peter Keller, PhD, Eleanor Setton, PhD

ABSTRACT

OBJECTIVES: To explore differences in urban versus rural lifetime excess risk of cancer from five specific contaminants found in food and beverages.

METHODS: Probable contaminant intake is estimated using Monte Carlo simulations of contaminant concentrations in combination with dietary patterns. Contaminant concentrations for arsenic, benzene, lead, polychlorinated biphenyls (PCBs) and tetrachloroethylene (PERC) were derived from government dietary studies. The dietary patterns of 34 944 Canadians from 10 provinces were available from Health Canada's Canadian Community Health Survey, Cycle 2.2, Nutrition (2004). Associated lifetime excess cancer risk (LECR) was subsequently calculated from the results of the simulations.

RESULTS: In the calculation of LECR from food and beverages for the five selected substances, two (lead and PERC) were shown to have excess risk below 10 per million; whereas for the remaining three (arsenic, benzene and PCBs), it was shown that at least 50% of the population were above 10 per million excess cancers. Arsenic residues, ingested via rice and rice cereal, registered the greatest disparity between urban and rural intake, with LECR per million levels well above 1000 per million at the upper bound. The majority of PCBs ingestion comes from meat, with values slightly higher for urban populations and LECR per million estimates between 50 and 400. Drinking water is the primary contributor of benzene intake in both urban and rural populations, with LECR per million estimates of 35 extra cancers in the top 1% of sampled population.

CONCLUSION: Overall, there are few disparities between urban and rural lifetime excess cancer risk from contaminants found in food and beverages. Estimates could be improved with more complete Canadian dietary intake and concentration data in support of detailed exposure assessments in estimating LECR.

KEY WORDS: Risk assessment; diet; carcinogens; urban health; rural health

La traduction du résumé se trouve à la fin de l'article.

Can J Public Health 2017;108(3):e288–e295
doi: 10.17269/CJPH.108.5830

There is evidence that diets and health outcomes are related to geographic location; for example, there may be differences between urban versus rural populations. Some studies confirm that rural diets, with greater access to fresh, locally grown produce, contain more fruits and vegetables than urban counterparts;[1] although other studies report minimal differences,[2] or the reverse, i.e., that rural diets lack adequate nutrition to maintain good health.[3] Rural populations in the United States (23.3% compared to 20.5% for urban populations)[4] reportedly show increased incidences of obesity, which have been ascribed by some to poor diet.[5] Monroe et al. report that cancer risk may be greater for urban populations, however, rural populations are more vulnerable to contracting chronic diseases, being "older, poorer and less educated".[6] Other urban-rural health differences show certain cancers (stomach and lung) have a higher rate of incidence for rural inhabitants; whereas, breast cancer and heart disease are more prevalent for urbanites.[7,8]

The objective of this paper is to conduct preliminary probabilistic modelling of intake for selected known (arsenic, benzene, polychlorinated biphenyls (PCBs)) or suspected (lead, tetrachloroethylene (PERC)) carcinogens, as classified by the International Agency for Research on Cancer,[9] that have been detected in North American foods, with a specific focus on differences between Canadians living in urban versus rural areas. We hypothesize that rural residents, when compared to urban residents, consume different foods in different amounts, and therefore may have different associated intakes and risks. The results of this study will serve to highlight important information gaps and identify potential priorities for more detailed exposure assessments. This study is the first to look at dietary intake of carcinogens and lifetime excess cancer risk disparities between urban and rural populations in Canada.

METHODS

We employ a probabilistic approach to estimate the range and frequency of possible daily contaminant intakes for urban versus rural Canadians, and associate these intake levels with lifetime excess cancer risk (LECR). We then compare our results to the current Health Canada guideline that suggests that 10 extra cancers per one million people is a negligible risk.[10] Daily dietary intake is determined by:

Author Affiliations

Department of Geography, University of Victoria, Victoria, BC
Correspondence: Eleanor Setton, PhD, Department of Geography, University of Victoria, PO Box 3060 Ring Road, Victoria, BC V8N 1V3, Tel: 250-853-3819, E-mail: elsetton@uvic.ca

Conflict of Interest: None to declare.

$$\text{Food group intake} = \sum (F_1 \times C_1 \times \text{DF}_1) + (F_2 \times C_2 \times \text{DF}_2) + \ldots (F_n \times C_n \times \text{DF}_n) \quad \text{[Eq. 1]}$$

where F is the amount of specific food or beverage consumed in g/day, C is the concentration of contaminant in μg/g (Table 1), DF is the detection frequency (no. of detections/no. of samples) and n is the n^{th} food in a group.

Each food group intake was then summed to determine total intake for each substance. To estimate potential risk from long-term ingestion of carcinogens via diet, LECR is used as an indicator of potential cancers occurring in a population. LECR assumes that the lifetime average daily intake is the same for 70 years. It is calculated by multiplying the estimated total intake by a cancer potency factor (CPF) which produces an estimate of the LECR:[10]

$$\text{LECR per million} = 1\,000\,000/(\text{ADI} \times \text{CPF}) \quad \text{[Eq. 2]}$$

where ADI is the average daily intake in mg/kg of body weight, and CPF is the cancer potency factor (also called oral slope factor).

For this study, body weight (bw) is assumed to be 70 kg, as per Health Canada's standards for exposure assessment.[10] LECR for each contaminant was generated using CPFs from Health Canada,[11] the California Office of Environmental Health Hazard Assessment (CA-OEHHA),[12] and the US Environmental Protection Agency (US-EPA).[13] When more than one CPF was available, we used the highest value (Table 2). We assumed that only 40% of total arsenic intake was of the inorganic (carcinogenic) form.[14]

We used the most current available Canadian consumption data (g/day) from the 24-hour dietary recall of representative populations from the Canadian Community Health Survey (CCHS), Cycle 2.2, Nutrition (2004), a national canvassing of 34 944 adult respondents from 10 provinces.[15] Using data fields provided within the dataset (sample id; urban; rural; food items, grams consumed) and based on a 24-hour dietary recall survey, the records were coded as urban (n = 27 144; 77.7%) or rural (n = 7800; 22.3%) and analyzed separately. Urban and rural are defined in the CCHS by population concentration and density, where urban is regarded as continuously built-up areas with a population concentration of 1000+ and a population density of 400+ per square kilometre. All other areas are considered rural.[16] This split closely matches the Canadian Council on Social Development's finding that 79.6% of Canada's 2001 census population resided in urban centres, while 20.4% lived in rural locations.[17]

The CCHS survey includes the Bureau of Nutritional Sciences (BNS) food list, with approximately 232 food products in 78 food groupings, some whole (e.g., apples) and some prepared (e.g., vegetable soup). Using the BNS data, we excluded prepared foods (134 items) in our model, given the difficulties in establishing the ingredients and proportions thereof. We do include 60 whole foods, aggregated into 8 food groups as shown in Table 3.

We used measured data from three sources. The Canadian Food Inspection Agency (CFIA) – National Chemical Residue Monitoring Program (NCRMP): 2012–2013 Annual Report included data on total arsenic and lead in numerous foods.[18] The U.S. Food and Drug Administration (US FDA) – Total Diet Study (TDS) – Market Baskets 1991–1993 and 2003–2004: Revision December 2006 included data on benzene, PCBs and PERC.[19] Additional data for arsenic and lead were reported in the U.S. Food and Drug Administration – Elements Results Summary – Market Baskets 2006 through 2011.[20] The minimum, mean and maximum concentration of the selected contaminants for individual foods were matched to our food list to produce model inputs for amounts consumed with associated contaminant concentration.[21]

A probabilistic risk model developed with @RISK software was used to conduct Monte Carlo simulation analysis for urban and rural intake. For our study, a dietary record was selected at random for each sample set (i.e., an iteration), then for each food reported as being consumed, a random value for the concentration value was generated based on a Project Evaluation and Review Technique (PERT) distribution, and eq. 1 was calculated. Population weights provided by CCHS were used to guide the probability of selecting any particular dietary record. A population weight variable for each respondent was also provided in the CCHS. The population weight "corresponds to the number of persons in the entire population that are represented by the respondent".[22] In the Monte Carlo simulation, records with a higher given sample weight have a greater probability of being chosen, as they represent a greater proportion of the entire population. We ran 50 000 iterations for each substance, using both the urban and rural dietary records respectively for a total of 10 unique simulations, producing distributions of the resulting intake values. Finally, we calculated LECR for key categories of each distribution, using available CPFs.

RESULTS

Total intake (μg/day) for urban versus rural residents for each carcinogen is shown in Figure 1 and Table 4.

The major food group contributors for each contaminant are listed in Table 5.

Arsenic intake levels show the greatest absolute disparity between urban and rural populations. The median daily intake was estimated at 7.4 μg/day (95% CI: 7.3–7.6) for urban compared to 4.8 μg/day (95% CI: 4.7–4.9) for rural. Recognizing that inorganic arsenic levels may be much lower than 40%,[23,24] an analysis assuming 20% in general would reduce average intakes to ~0.4 and ~0.3 μg/day respectively.

Benzene intake levels from food and beverages were similar for urban and rural populations. The median intake was estimated at 10.1 μg/day (95% CI: 10.0–10.1) for urban residents and 10.2 μg/day (95% CI: 10.1–10.3) for rural.

Lead intake levels from food and beverages were the same for urban and rural populations in all percentiles. The median intake was estimated at 1.9 μg/day (95% CI: 1.8–1.9) for urban and 1.9 μg/day (95% CI: 1.8–1.9) for rural.

PCBs intake levels from food and beverages were the same for urban and rural populations in all percentiles. The median intake was estimated at 2.0 μg/day (95% CI: 1.9–2.0) for urban and 2.0 μg/day (95% CI: 2.0–2.1) for rural (Table 4). PERC intake levels from food and beverages were slightly higher for rural populations than for urban. The median intake was estimated at 0.9 μg/day (95% CI: 0.7–0.8) for rural and 0.8 μg/day (95% CI: 0.9–0.9) for urban. Although urban consumed a higher percentage of dairy (41.0% vs. 40.7%), the overall intake from the other food categories was higher for rural.

Table 1. Concentration of contaminant in μg/g (*C*)

Food group	Arsenic (μg/g)				Lead (μg/g)				Benzene (μg/g)				PCBs (μg/g)				PERC (μg/g)			
	Mean	Min	Max	DF	Mean	Min	Max	DF	Mean	Min	Max	DF	Mean	Min	Max	DF	Mean	Min	Max	DF
Meat																				
Bacon	–	–	–	–	0.001	0.000	0.021	0.042	0.002	0.001	0.017	0.864	–	–	–	–	0.002	0.000	0.022	0.977
Beef	0.002	0.000	0.014	0.125	0.001	0.000	0.018	0.083	0.020	0.001	0.099	0.455	0.020	0.020	0.020	1.000	–	–	–	–
Chicken meat	0.010	0.005	0.048	0.314	0.010	0.010	0.010	0.020	0.036	0.036	0.036	0.977	0.030	0.030	0.030	1.000	–	–	–	–
Cured ham	–	–	–	–	0.001	0.000	0.023	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Ground beef	–	–	–	–	–	–	–	–	0.016	0.003	0.190	0.477	–	–	–	–	0.002	0.000	0.006	0.977
Lamb	–	–	–	–	0.001	0.000	0.015	0.042	–	–	–	–	0.010	0.010	0.010	1.000	–	–	–	–
Lean beef	0.009	0.007	0.012	0.250	0.002	0.002	0.002	0.023	–	–	–	–	0.010	0.010	0.010	1.000	0.003	0.003	0.003	1.000
Lean lamb	–	–	–	–	0.001	0.000	0.015	0.042	–	–	–	–	0.010	0.010	0.010	1.000	–	–	–	–
Lean pork	0.007	0.006	0.007	0.058	0.010	0.010	0.010	0.019	0.002	0.030	0.048	0.955	0.010	0.010	0.010	1.000	–	–	–	–
Lean veal	0.006	0.006	0.007	0.188	0.002	0.002	0.002	0.063	–	–	–	–	0.010	0.010	0.010	1.000	–	–	–	–
Liver	–	–	–	–	0.001	0.000	0.023	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Pork	–	–	–	–	–	–	–	–	–	–	–	–	0.020	0.020	0.020	1.000	–	–	–	–
Turkey with skin	0.010	0.005	0.028	0.415	0.002	0.002	0.002	0.024	0.034	0.034	0.034	0.977	–	–	–	–	–	–	–	–
Turkey meat	0.010	0.005	0.028	0.415	0.002	0.002	0.002	0.024	0.034	0.034	0.034	0.977	–	–	–	–	–	–	–	–
Fish																				
Fish	0.305	0.000	0.436	0.958	–	–	–	–	–	–	–	–	0.024	0.009	0.055	0.375	–	–	–	–
Dairy																				
Butter	–	–	–	–	0.002	0.000	0.031	0.083	0.003	0.001	0.022	0.795	0.003	0.020	0.120	0.977	0.009	0.003	0.102	0.432
Cottage cheese	–	–	–	–	0.000	0.000	0.009	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Egg	0.020	0.011	0.032	0.281	0.042	0.008	0.104	0.175	–	–	–	–	–	–	–	–	–	–	–	–
Half & half	–	–	–	–	0.001	0.000	0.024	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Ice cream	–	–	–	–	0.000	0.000	0.009	0.042	0.001	0.002	0.014	0.932	–	–	–	–	0.002	0.000	0.006	0.977
Lite cheese	0.001	0.000	0.022	0.042	–	–	–	–	0.001	0.000	0.009	0.955	–	–	–	–	0.002	0.002	0.002	1.000
Margarines	–	–	–	–	0.001	0.000	0.033	0.042	0.003	0.001	0.030	0.818	–	–	–	–	0.003	0.002	0.042	0.886
Regular cheese	0.026	0.015	0.047	0.429	1.704	1.139	2.221	0.857	0.003	0.001	0.047	0.886	–	–	–	–	0.000	0.002	0.008	0.977
Sour cream	–	–	–	–	0.001	0.000	0.034	0.042	0.002	0.003	0.020	0.909	–	–	–	–	0.007	0.007	0.007	0.977
Whole milk	0.011	0.010	0.020	0.143	0.012	0.010	0.020	0.024	0.000	0.001	0.008	0.977	–	–	–	–	0.003	0.003	0.003	1.000
Fruits																				
Apple	0.011	0.005	0.028	0.075	0.004	0.001	0.021	0.597	0.002	0.001	0.032	0.886	–	–	–	–	–	–	–	–
Banana	–	–	–	–	–	–	–	–	0.034	0.001	0.136	0.432	–	–	–	–	–	–	–	–
Cherries	–	–	–	–	–	–	–	–	0.016	0.016	0.016	0.971	–	–	–	–	–	–	–	–
Citrus fruits	–	–	–	–	0.001	0.000	0.021	0.083	0.001	0.001	0.015	0.886	–	–	–	–	–	–	–	–
Melons	0.006	0.000	0.024	0.500	0.000	0.000	0.010	0.042	0.013	0.013	0.013	0.977	–	–	–	–	–	–	–	–
Peaches	0.018	0.018	0.018	0.333	–	–	–	–	0.027	0.027	0.027	0.977	–	–	–	–	–	–	–	–
Pears	–	–	–	–	0.001	0.000	0.009	0.083	0.018	0.018	0.018	0.977	–	–	–	–	–	–	–	–
Plums	–	–	–	–	–	–	–	–	0.013	0.013	0.013	0.974	–	–	–	–	–	–	–	–
Raisins	0.007	0.000	0.031	0.250	0.005	0.000	0.023	0.333	0.005	0.001	0.097	0.795	0.010	0.010	0.010	1.000	0.011	0.011	0.011	0.977
Strawberries	0.010	0.010	0.010	0.143	0.004	0.001	0.009	0.857	0.001	0.001	0.020	0.930	–	–	–	–	0.005	0.005	0.005	1.000
Vegetables																				
Beans	0.007	0.007	0.007	0.200	0.008	0.002	0.024	0.800	–	–	–	–	–	–	–	–	–	–	–	–
Broccoli	0.002	0.000	0.010	0.042	0.003	0.001	0.005	1.000	–	–	–	–	–	–	–	–	–	–	–	–
Cabbage	0.004	0.004	0.004	0.200	0.002	0.001	0.003	0.600	–	–	–	–	–	–	–	–	–	–	–	–
Carrots	0.007	0.006	0.008	0.250	0.003	0.001	0.006	0.667	–	–	–	–	–	–	–	–	–	–	–	–
Celery	0.007	0.007	0.007	1.000	0.006	0.006	0.006	1.000	–	–	–	–	–	–	–	–	–	–	–	–
Corn	0.001	0.000	0.013	0.042	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
French fries	–	–	–	–	–	–	–	–	0.004	0.002	0.058	0.773	–	–	–	–	0.002	0.000	0.008	0.932
Mushrooms	0.014	0.005	0.030	0.889	0.002	0.001	0.004	0.556	–	–	–	–	–	–	–	–	–	–	–	–
Onions	0.009	0.009	0.009	0.250	0.005	0.002	0.009	0.500	–	–	–	–	–	–	–	–	–	–	–	–
Peas	–	–	–	–	0.005	0.002	0.012	1.000	–	–	–	–	–	–	–	–	–	–	–	–
Peppers	0.007	0.007	0.007	0.143	0.006	0.006	0.006	0.143	–	–	–	–	–	–	–	–	–	–	–	–
Potatoes	0.007	0.004	0.016	0.196	0.004	0.001	0.019	0.761	0.014	0.014	0.014	0.977	–	–	–	–	–	–	–	–
Squashes	–	–	–	–	0.006	0.004	0.007	1.000	0.014	0.014	0.014	0.977	–	–	–	–	–	–	–	–
Tomatoes	–	–	–	–	0.012	0.001	0.037	0.800	0.004	0.001	0.067	0.864	–	–	–	–	–	–	–	–
Rice/cereals																				
Rice	0.065	0.036	0.094	1.000	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–	–
Rice cereal	0.161	0.000	0.505	0.958	0.001	0.000	0.013	0.083	–	–	–	–	–	–	–	–	–	–	–	–

Continued

Table 1. (Continued)

Food group	Arsenic (µg/g)				Lead (µg/g)				Benzene (µg/g)				PCBs (µg/g)				PERC (µg/g)			
	Mean	**Min**	**Max**	**DF**	**Mean**	**Min**	**Max**	**DF**	**Mean**	**Min**	**Max**	**DF**	**Mean**	**Min**	**Max**	**DF**	**Mean**	**Min**	**Max**	**DF**
Pasta	–	–	–	–	0.001	0.000	0.027	0.083	–	–	–	–	–	–	–	–	–	–	–	–
Wholegrain cereals	0.027	0.000	0.054	0.917	0.001	0.000	0.023	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Grains/nuts																				
Peanut butter	0.005	0.000	0.037	0.167	–	–	–	–	0.003	0.001	0.025	0.841	–	–	–	–	0.002	0.000	0.007	0.977
White bread	–	–	–	–	0.000	0.000	0.011	0.042	0.002	0.001	0.025	0.886	–	–	–	–	0.005	0.005	0.005	1.000
Whole wheat breads	0.004	0.000	0.012	0.333	0.001	0.000	0.011	0.083	–	–	–	–	–	–	–	–	–	–	–	–
Beverages																				
Beers	–	–	–	–	0.000	0.000	0.006	0.083	–	–	–	–	–	–	–	–	–	–	–	–
Tap and well water	–	–	–	–	–	–	–	–	0.003	0.005	0.006	0.750	–	–	–	–	–	–	–	–
Tea	–	–	–	–	0.000	0.000	0.010	0.042	–	–	–	–	–	–	–	–	–	–	–	–
Wine	0.008	0.000	0.018	0.750	0.007	0.000	0.029	0.875	–	–	–	–	–	–	–	–	–	–	–	–

DF = detection frequency; PCB = polychlorinated biphenyls; PERC = tetrachloroethylene.

Table 2. Cancer potency factors

Substance	Health Canada	CA-OEHHA	US-EPA
Arsenic	**1.8**	1.5	1.5
Benzene	**0.0834**	–	0.055
Lead	–	**0.0085**	–
PCBs	–	**2.0**	**2.0**
PERC	–	**0.051**	0.0021

Note: Bold indicates used in analysis.
CA-OEHHA = California Office of Environmental Health Hazard Assessment; US-EPA = US Environmental Protection Agency.

Table 3. Included foods and food groups

Group	Individual foods
Meat	Bacon; beef; lean beef, chicken meat; cured ham; ground beef; lamb; lean lamb; pork; lean pork; lean veal; liver; turkey with skin; turkey meat
Fish	Fish
Dairy	Butters; cottage cheese; eggs; half & half; ice cream; lite cheese; regular cheese; sour cream; margarines; whole milk
Fruit	Apples; bananas; cherries; citrus fruits; melons; peaches; pears; plums; raisins; strawberries
Vegetables	Beans; broccoli; cabbage; carrots; celery; corn; French fries; mushrooms; onions; peas; peppers; potatoes; squashes; tomatoes
Rice/cereals	Rice cereals; pasta; rice; wholegrain cereals
Grains/nuts	Peanut butter; white breads; whole wheat bread
Beverages	Tap and well water; tea; beers; wines

LECR estimates for lead and PERC suggest excess cancer risk below 10 per million due to dietary intake; however, intakes of three carcinogens – arsenic, benzene and PCBs – produced LECR estimates above 10 per million (Table 6). Between 50% and 60% of the estimated intakes for arsenic (assuming 40% as inorganic form) resulted in LECR values above 10 per million, based on Health Canada's cancer potency factor (1.8).[25] Due to differences in daily arsenic intake estimated, the LECR values are on average 1.5 times higher at every percentile for urban dwellers than for rural, and reach 772 per million at the 99th percentile for the urban sample. Similarly, 60% of the PCB LECR values, based on cancer potency factors from CA-OEHHA (2.0),[25] were above 10 per million for both urban and rural populations, at approximately 15–19 extra cancers per million respectively and 99th percentile LECRs of 378–440 per million. LECR estimates associated with benzene intake are based on Health Canada's cancer potency factor (0.0834).[25] Approximately 40% of LECR estimates due to benzene intakes are above 10 per million, although 99th percentile level only reaches 51–55 per million.

DISCUSSION

The objective of this paper was to compare urban versus rural lifetime excess cancer risk from food and beverages using a preliminary Monte Carlo probabilistic risk model to estimate contaminant intakes of arsenic, benzene, lead, PCBs and PERC. With the caveat of using a relatively limited data set in terms of foods and residue measures, we found that between 40% and 50% of the population simulated had intakes of arsenic, PCBs and benzene associated with LECRs of greater than 10 per million. This suggests the need for more detailed investigation of potential

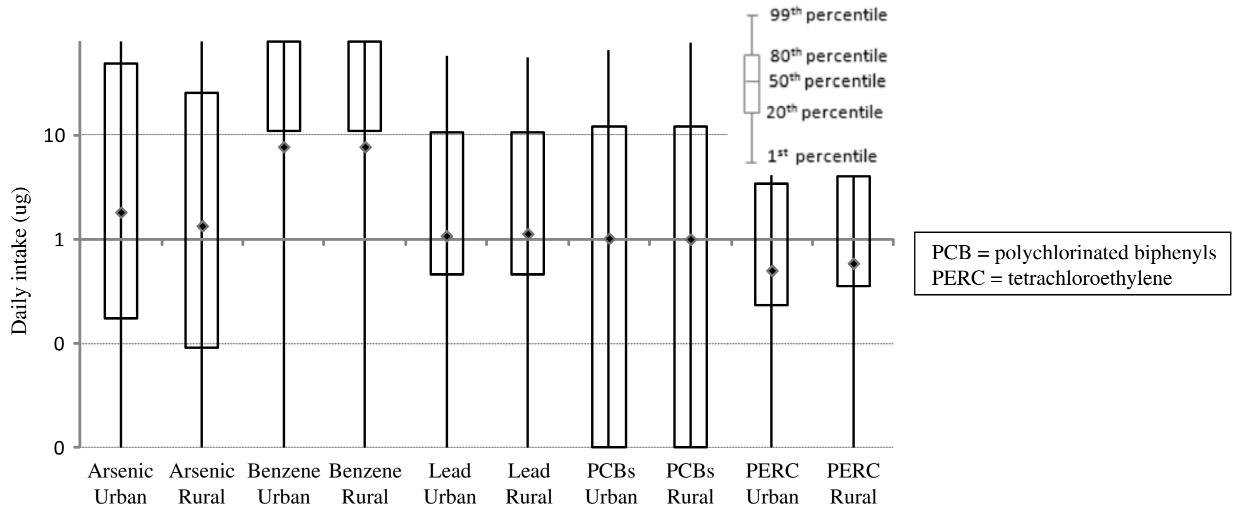

Figure 1. Urban and rural intake

Table 4. Urban and rural intake (µg/day)

	Arsenic urban	Arsenic rural	Benzene urban	Benzene rural	Lead urban	Lead rural	PCBs urban	PCBs rural	PERC urban	PERC rural
Min	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Q1	0.1	0.1	3.1	3.1	0.2	0.2	0.01	0.01	0.1	0.2
Med	1.8	1.3	7.7	7.7	1.1	1.1	1.0	1.0	0.5	0.6
Q3	10.6	6.2	15.6	15.5	3.0	3.0	3.4	3.4	1.2	1.4
Max	75.1	53.4	42.8	46.0	11.9	11.6	13.2	15.4	4.6	5.8

Min/Med/Max = minimum/medium/maximum; Q = quarter.

Table 5. Major food group contributors to contaminant intake

		Urban		Rural	
Rank	**Food groups**	**Mean intake**	**Comp%***	**Mean intake**	**Comp%**
Arsenic					
1	Cereal/rice	5.0	66.6%	2.5	51.4%
2	Fish/seafood	1.1	14.9%	1.0	20.3%
3	Dairy	0.4	5.6%	0.5	9.4%
Benzene					
1	Beverages	3.9	38.6%	3.9	38.1%
2	Meat	2.3	22.9%	2.3	22.3%
3	Fruit	1.9	19.1%	N/A	
3	Vegetables	N/A		1.7	17.0%
Lead					
1	Vegetables	1.1	55.9%	1.1	57.3%
2	Dairy	0.3	16.1%	0.3	17.4%
3	Beverages	0.3	14.1%	0.2	11.8%
PCBs					
1	Meat	1.7	85.6%	1.7	84.6%
2	Dairy	0.2	7.6%	0.2	9.0%
3	Fruit	0.1	4.9%	0.1	4.4%
PERC					
1	Dairy	0.3	41.0%	0.4	40.7%
2	Grains/nuts	0.2	20.7%	0.2	22.5%
3	Fruit	0.1	17.7%	N/A	
3	Meat	N/A		0.2	16.6%

* Comp% = Component percent.

Table 6. Lifetime excess cancer risk estimates for arsenic, PCBs and PERC

	Lifetime excess cancer risk (per million)					
	Arsenic		PCBs		Benzene	
Percentile	**Urban**	**Rural**	**Urban**	**Rural**	**Urban**	**Rural**
1	0.0	0.0	0.0	0.0	0.1	0.1
5	0.0	0.0	0.0	0.0	0.9	0.9
10	0.0	0.0	0.0	0.0	1.9	1.9
20	1.1	0.6	0.0	0.0	3.7	3.7
30	4.8	3.3	5.1	5.3	5.5	5.3
40	**10.3**	7.8	**15.0**	**14.7**	7.2	7.1
50	**18.6**	**13.8**	**29.1**	**28.6**	9.2	9.2
60	**32.4**	**22.1**	**45.7**	**45.4**	**11.5**	**11.5**
70	**58.4**	**35.2**	**68.2**	**65.5**	**14.5**	**14.4**
80	**108.9**	**63.3**	**97.1**	**96.4**	**18.5**	**18.5**
90	**211.5**	**127.8**	**148.6**	**151.4**	**25.3**	**25.7**
95	**335.4**	**202.1**	**207.3**	**211.5**	**32.5**	**33.2**
96	**382.4**	**235.4**	**226.1**	**235.4**	**34.9**	**35.5**
97	**455.1**	**289.6**	**252.0**	**252.4**	**38.2**	**39.3**
98	**557.1**	**379.4**	**296.4**	**305.1**	**43.0**	**45.2**
99	**772.2**	**549.0**	**378.4**	**440.5**	**51.0**	**54.8**

Note: Bold values signify the percentile of the population that exceed Health Canada's LECR threshold of 10 per million excess cancers.

arsenic, PCBs and benzene exposure via foods and beverages in Canada.

It is challenging to compare the results from our study with other similar studies when the variables are so diverse: number of foods surveyed and tested; actual or hypothesized sample population; size of the sample population; testing methods; model used; etc. For example, in the case of arsenic intake, based on actual dietary patterns from 60 foods, we estimated total arsenic intakes of approximately 25–75 µg/day, only above the 80th percentile. In comparison, a US study incorporating 264 foods reported an average (i.e., 50th percentile) intake of 27.5 μg/day,[14] while a study from Chile estimated an average intake of 77.0 μg/day from 300 foods.[26] Health Canada has reported results indicating average daily intakes ranging between 0.3 and 0.4 μg/kg bw;[27] assuming the standard body weight of 70 kg,[10] this translates to 17.5–25.2 μg/day respectively, which is similar to our estimates near the 85th percentile. The US and Chilean studies estimated total arsenic intake for an average consumer; whereas, our study was based on actual dietary patterns from the Canadian population simulated in our risk model.

The predominant route of exposure to benzene is via inhalation (cigarette smoke, air pollution), with previous studies reporting that food does not represent a significant source of human exposure.[28] Our study found that daily intakes ranged between a minimum of 0.04 μg/day (urban) and 0.1 μg/day (rural) to a maximum of 42.8 μg/day (urban) and 46.0 μg/day (rural) at the 99th percentile with a mean value of 7.70 μg/day for both urban and rural cohorts. While we could not find recent Canadian or American studies addressing human dietary intake of benzene,[28] a study from Belgium notes average benzene intake for all foods averaged 1.4 μg/day (0.02 μg/kg bw/day).[29] This probabilistic study focussed on processed, canned and bottled foods known to contain some form of benzene (benzoic acid; added benzoate; etc.), testing 455 food samples for specific benzene content. Data on food consumption were obtained from a national survey, in which 3083 participants completed a two-day 24-hour recall self-reporting food frequency questionnaire. This approach does not indicate grams per day consumed, only servings per day, which may under- or over-estimate actual intake. This variation in intake values may be attributable to differing approaches or methodologies in estimating dietary intake and differences in food surveys or contaminant quantification.[29]

The daily dietary intake of lead was estimated in the current study to range from a minimum value of 0.00 μg/day for both urban and rural populations to a maximum of 11.9 and 11.6 μg/day (99th percentile), with mean values of 1.1 and 1.1 μg/day respectively, suggesting negligible differences. Findings for lead reported here are significantly lower than have been reported in other recent studies. Turconi (2009), surveying a total of 1978 subjects in Northern Italy, estimated a range between 25.8 and 66.6 μg/day.[30] This study analyzed 248 prepared and processed foods, where consumption was based on frequency and general portion sizing, and exposure was estimated on the average amount of food ingested, not actual amounts (g/day). Munoz (2005), from a study in Chile involving 300 food items, estimated a daily adult intake of lead from food at a maximum of 206.0 μg/day.[26] This deterministic study was based on food frequency and portion sizing rather than actual amounts of food consumed. Health Canada, in the 2013 report, approximated the mean daily intake of lead from dietary sources to be 7.0 μg/day (0.1 μg/kg bw/day at 70 kg) based on average daily food intake and body weight of Canadians of all ages.[31] In our assessment, the average lead intake reached the equivalent that Health Canada estimates at the 96th percentile (7.3 μg/day). Our study results are calculated on actual individual dietary patterns, providing a more realistic estimate of exposure and associated risk.

The current study showed that PCBs intake ranged from the estimated minimum of 0.0 μg/day for both urban and rural populations to a maximum intake value (99th percentile) of 13.2 and 15.4 μg/day respectively, with averages at 1.0 μg/day (urban) and 1.0 μg/day (rural). One food-market basket study from Belgium estimates the mean daily PCB intake for all foods to be 0.47 μg/day (470 ng/day). However, this value is based on estimated average daily food intakes by a theoretical person and a deterministic method was used in the calculations.[32] Our results include the dietary intake for ~35 000 respondents from across the 10 provinces, and actual daily food amounts consumed compiled using probabilistic techniques, thus making comparisons difficult. A 2009 study based on a seven-day food consumption survey from France found the mean dietary intake of PCBs from 22 food groups, including 1665 food samples tested, to be 0.5 μg/day (7.7 ng/kg bw/day at 70 kg).[33] This study included both whole and processed foods, and actual body weights were used in assessing probable intake. In our assessment, the average intake to equate with some of these studies falls between the 30th and 50th percentiles at 0.2 and 0.5 μg/day respectively.

Human exposure to PERC is generally due to inhalation of polluted air or ingestion from contaminated waters and soil which may seep into the food chain; however, food is not considered a major route of PERC exposure.[34] This assessment, measured in 15 of 60 foods, found dairy to be the major dietary contributor to PERC intake. The minimum daily PERC intake was the same (0.0 μg/day) for urban and rural; however, there were slight differences at the 99th percentile, with 4.6 μg/day for urban and 5.8 μg/day for rural; the daily average was 0.5 μg/day (urban) and 0.6 μg/day (rural). In a 1993 assessment report, Health Canada estimated the average adult daily PERC intake from a composite of food groups to be 8.4 μg/day (0.12 μg/kg bw/day at 70 kg).[34] These HC data are from studies and information from the 1980s and 1990s, which may not be relevant today based on average levels ingested by average Canadians and not actual consumption. Our assessment was based on actual dietary patterns and the estimated LECR levels, which fell well below the 10 per million recommended by Health Canada.

Limitations of the study

There are limitations and biases that need to be taken into account regarding our analysis. We used data for 60 whole foods and beverages; however, using alternative food lists could produce different results. The concentration values measured in various foods could not be differentiated between urban and rural settings and so our results are based only on differences in consumption patterns. We assumed on average each respondent weighed 70 kg. This could overestimate intake per kilogram of body weight for some respondents, while underestimating for others. This preliminary analysis should be considered screening level, as a more refined estimate of individual doses may provide different results. The dietary patterns are more than 10 years old, and in the absence of an updated survey, it is unknown how well these patterns reflect current diets.

More detailed exposure assessments would be better supported with more extensive and complete dietary intake and concentration data. Canadian Total Diet Studies, conducted under the auspices of Health Canada and its Bureau of Chemical Safety, have been conducted since 1969; however, these surveys are very narrow in scope, usually focusing on one or two cities per year, then releasing data for only a few substances, i.e., radionuclides and/or trace elements.[35] For example, the 1990s surveys focused on pesticides, PCBs, dioxins and furans in various Canadian cities, with the last analysis done in 1998 in Whitehorse, NWT.[35] Since 2000, a shift has been made to detect trace elements and radionuclides (the latest taking place in Montreal in 2013, radionuclides only), thereby making it difficult to ascertain any level of known or suspected carcinogenic substances in the Canadian food chain or any substantive consumption amounts.[35]

Future directions in improving health risk assessment for food and beverages in Canada may include: establishing or adopting (from the US or the EU community) a standardized food-item listing with clear and concise definitions; establishing or adjusting a more robust food consumption survey system (from existing US or EU systems) to suit Canadian criteria; enhancing the existing Total Diet Study program of food contaminant residues to include known or suspected carcinogens and provide greater national coverage; harmonizing databases between agencies and research groups; and developing and/or utilizing tools and technology to become proactive in the analysis of food safety and health risks from the accumulated effects of multiple exposures to chemicals and/or environmental contaminants in the food supply. Reliable data modelling can provide cancer prevention policy and decision makers with information regarding potential health risk areas, allowing efforts to be prioritized in reducing exposure via ingestion.

REFERENCES

1. Morton LW, Bitto EA, Oakland MJ, Sand M. Accessing food resources: Rural and urban patterns of giving and getting food. *Agric Human Values* 2008; 25(1):107–19. doi: 10.1007/s10460-007-9095-8.
2. Dean WR, Sharkey JR. Rural and urban differences in the associations between characteristics of the community food environment and fruit and vegetable intake. *J Nutr Educ Behav* 2011;43(6):426–33. PMID: 21616721. doi: 10.1016/j.jneb.2010.07.001.
3. Ostry A, Morrision K. A method for estimating the extent of regional food self-sufficiency and dietary ill health in the province of British Columbia, Canada. *Sustain* 2013;5(11):4949–60. doi: 10.3390/su5114949.
4. Jackson J, Doescher M, Jerant AF, Hart L. A national study of obesity prevalence and trends by type of rural county. *J Rural Health* 2005;21:140–48. PMID: 15859051. doi: 10.1111/j.1748-0361.2005.tb00074.x.
5. Hill JL, You W, Zoellner JM. Disparities in obesity among rural and urban residents in a health disparate region. *BMC Public Health* 2014;14(1):1051. PMID: 25297840. doi: 10.1186/1471-2458-14-1051.
6. Monroe AC, Ricketts TC, Savitz LA. Cancer in rural versus urban populations: A review. *J Rural Health* 1992;8(3):212–20. PMID: 10121550. doi: 10.1111/j.1748-0361.1992.tb00354.x.
7. Pampalon R, Martinez J, Hamel D. Does living in rural areas make a difference for health in Québec? *Health Place* 2006;12(4):421–35. PMID: 15955720. doi: 10.1016/j.healthplace.2005.04.002.
8. Sharp L, Donnelly D, Hegarty A, Carsin AE, Deady S, McCluskey N, et al. Risk of several cancers is higher in urban areas after adjusting for socioeconomic status. Results from a two-country population-based study of 18 common cancers. *J Urban Health* 2014;91(3):510–25. PMID: 24474611. doi: 10.1007/s11524-013-9846-3.
9. IARC. *Agents Classified by the IARC Monographs, Volumes 1–114*, 2015.
10. Health Canada. *A Handbook for Exposure Calculations*. Ottawa, ON: Health Canada, 1995.
11. Health Canada. *Federal Contaminated Site Risk Assessment in Canada, Part II: Health Canada Toxicological Reference Values and Chemical-Specific Factors*. Ottawa, ON: Health Canada, 2010.
12. CA-OEHHA. *Hot Spots Unit Risk and Cancer Potency Values*. Sacramento, CA: California Environmental Protection Agency, 2011. Available at: https://oehha.ca.gov/ (Accessed September 8, 2016).
13. US EPA. *Integrated Risk Information System: CPFs*. Washington, DC: US Environmental Protection Agency, 2015. Available at: https://www.epa.gov/iris (Accessed September 8, 2016).
14. Tao SS, Bolger PM. Dietary arsenic intakes in the United States: FDA Total Diet Study, September 1991–December 1996. *Food Addit Contam* 1999;16:465–72. doi: 10.1080/026520399283759.
15. Health Canada. *Canadian Community Health Survey, Cycle 2.2, Nutrition (2004): A Guide to Accessing and Interpreting the Data*. Ottawa, ON: Health Canada, 2004. Available at: http://www.hc-sc.gc.ca/fn-an/surveill/nutrition/commun/cchs_guide_escc-eng.php (Accessed September 8, 2016).
16. Health Canada. *Canadian Community Health Survey, Cycle 2.2, Nutrition (2004): Income-Related Household Food Security in Canada*. Ottawa, ON: Health Canada, 2007. H164-42/2007E-PDF.
17. Canadian Council on Social Development. *A Demographic Profile of Canada*. Kanata, ON: CCSD, 2004; 1–12.
18. Canadian Food Inspection Agency. *National Chemical Residue Monitoring Program 2012–2013 Report*. Ottawa, ON: CFIA, 2014. Available at: http://www.inspection.gc.ca/food/chemical-residues-microbiology/chemical-residues/ncrmp-report/eng/1415838181260/1415838265896 (Accessed September 8, 2016).
19. US FDA. *US Food and Drug Administration – Total Diet Study Market Baskets 1991–1993 through 2003–2004*. College Park, MD: USFDA, 2006.
20. US FDA. *Total Diet Study. Elements Results Summary Statistics. Market Baskets 2006 through 2011*. 2014. Available at: http://www.fda.gov/downloads/Food/FoodScienceResearch/TotalDietStudy/UCM184301.pdf (Accessed September 8, 2016).
21. Cheasley R. *Geographic Exposure and Risk Assessment for Food Contaminants in Canada*. 2016. Available at: http://hdl.handle.net/1828/7396 (Accessed September 8, 2016).
22. Statistics Canada. *Nutrition – General Health (Including Vitamin & Mineral Supplements) & 24-Hour Dietary Recall Components User Guide*. Ottawa, ON: Statistics Canada, 2008. Available at: http://www23.statcan.gc.ca/imdb-bmdi/pub/document/5049_D24_T9_V1-eng.pdf (Accessed September 8, 2016).
23. Jara EA, Winter CK. Dietary exposure to total and inorganic arsenic in the United States, 2006–2008. *Int J Food Contam* 2014;1(1):3. doi: 10.1186/s40550-014-0003-x.
24. Lynch HN, Greenberg GI, Pollock MC, Lewis AS. A comprehensive evaluation of inorganic arsenic in food and considerations for dietary intake analyses. *Sci Total Environ* 2014;496:299–313. PMID: 25089691. doi: 10.1016/j.scitotenv.2014.07.032.
25. CAREX Canada. *Surveillance of Environmental and Occupational Exposures for Cancer Prevention*. 2016. Available at: http://www.carexcanada.ca/en/.
26. Munoz O, Bastias JM, Araya M, Morales A, Orellana C, Rebolledo R, et al. Estimation of the dietary intake of cadmium, lead, mercury, and arsenic by the population of Santiago (Chile) using a Total Diet Study. *Food Chem Toxicol* 2005;43(11):1647–55. PMID: 15975702. doi: 10.1016/j.fct.2005.05.006.
27. Xue J, Zartarian V, Wang SW, Liu SV, Georgopoulos P. Probabilistic modeling of dietary arsenic exposure and dose and evaluation with 2003–2004 NHANES data. *Environ Health Perspect* 2010;118(3):345–50. PMID: 20194069. doi: 10.1289/ehp.0901205.
28. Health Canada. *Guidelines for Canadian Drinking Water Quality: Guideline Technical Document – Benzene*. 2009. Available at: https://www.canada.ca/en/health-canada/services/publications/healthy-living/guidelines-canadian-drinking-water-quality-guideline-technical-document-benzene.html (Accessed September 8, 2016).
29. Vinci R, Jacxsens L, Van Loco J, Matsiko E, Lachat C, de Schaetzen T, et al. Assessment of human exposure to benzene through foods from the Belgian market. *Chemosphere* 2012;88(8):1001–7. PMID: 22483726. doi: 10.1016/j.chemosphere.2012.03.044.
30. Turconi G, Minoia C, Ronchi A, Roggi C. Dietary exposure estimates of twenty-one trace elements from a Total Diet Study carried out in Pavia, Northern Italy. *Br J Nutr* 2009;101(8):1200–8. PMID: 19007448. doi: 10.1017/S0007114508055670.
31. Health Canada. *Final Human Health State of the Science Report on Lead*. Ottawa, ON: Health Canada, 2013.
32. Voorspoels S, Covaci A, Neels H. Dietary PCB intake in Belgium. *Environ Toxicol Pharmacol* 2008;25(2):179–82. PMID: 21783856. doi: 10.1016/j.etap.2007.10.013.
33. Arnich N, Tard A, Leblanc JC, Le Bizec B, Narbonne JF, Maximilien R. Dietary intake of non-dioxin-like PCBs (NDL-PCBs) in France, impact of maximum levels in some foodstuffs. *Regul Toxicol Pharmacol* 2009;54(3):287–93. PMID: 19464333. doi: 10.1016/j.yrtph.2009.05.010.
34. Health Canada. *Priority Substances List Assessment Report – Tetrachloroethylene*. Ottawa, ON: Health Canada, 1993.
35. Health Canada. *Canadian Total Diet Study*. Ottawa, ON: Health Canada, 2014. Available at: http://www.hc-sc.gc.ca/fn-an/surveill/total-diet/index-eng.php (Accessed September 8, 2016).

Received: August 9, 2016
Accepted: February 25, 2017

RÉSUMÉ

OBJECTIFS : Explorer les écarts dans le risque excédentaire à vie de cancer en zone urbaine et en zone rurale associé à cinq contaminants précis trouvés dans les aliments et les boissons.

MÉTHODE : Nous avons estimé l'absorption probable des contaminants à l'aide de simulations de Monte-Carlo portant sur les concentrations de contaminants combinées aux habitudes alimentaires. Les concentrations d'arsenic, de benzène, de plomb, de biphényles polychlorés (BPC) et de tétrachloréthylène (PERC) ont été dérivées d'études gouvernementales d'exposition par voie alimentaire. Les habitudes alimentaires de 34 944 Canadiens dans 10 provinces provenaient du cycle 2.2, Nutrition, de l'Enquête sur la santé dans les collectivités canadiennes de Santé Canada (2004). À partir des résultats des simulations, nous avons calculé le risque excédentaire à vie de cancer (REAVC) associé.

RÉSULTATS : Lorsque nous avons calculé le REAVC associé aux aliments et aux boissons pour les cinq substances choisies, nous avons obtenu un risque excédentaire inférieur à 10 par million pour deux substances (le plomb et le PERC); pour les trois autres substances (l'arsenic, le benzène et les BPC), au moins 50 % de la population était au-dessus du seuil de 10 cancers excédentaires par million. Les résidus d'arsenic, ingérés dans le riz et les céréales de riz, ont présenté la plus grande disparité entre les niveaux d'absorption en zone urbaine et rurale, avec un REAVC par million très au-dessus de 1 000 par million à la limite supérieure. La majorité des BPC ingérés le sont dans la viande, avec des valeurs légèrement supérieures dans les populations urbaines et un REAVC qui se situerait entre 50 et 400 par million. L'eau potable est la principale source d'absorption du benzène, tant dans les populations urbaines que rurales, avec un REAVC par million estimé à 35 cancers excédentaires dans le centile supérieur de la population échantillonnée.

CONCLUSION : Dans l'ensemble, il y a peu de disparités entre les zones urbaines et rurales pour ce qui est du risque excédentaire à vie de cancer associé aux contaminants trouvés dans les aliments et les boissons. Les estimations du REAVC pourraient être améliorées si l'on disposait de données plus complètes sur les apports alimentaires et les concentrations au Canada pour appuyer les évaluations approfondies de l'exposition.

MOTS CLÉS : évaluation des risques; régime alimentaire; cancérogènes; santé en zone urbaine; santé en zone rurale