Drinking water consumption patterns in Canadian communities (2001–2007)

S. M. Roche, A. Q. Jones, S. E. Majowicz, S. A. McEwen and K. D. M. Pintar

ABSTRACT

A pooled analysis of seven cross-sectional studies from Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia (2001 to 2007) was performed to investigate the drinking water consumption patterns of Canadians and to identify factors associated with the volume of tap water consumed. The mean volume of tap water consumed was 1.2 L/day, with a large range (0.03 to 9.0 L/day). In-home water treatment and interactions between age and gender and age and bottled water use were significantly associated with the volume of tap water consumed in multivariable analyses. Approximately 25% (2,221/8,916) of participants were classified as bottled water users, meaning that 75% or more of their total daily drinking water intake was bottled. Approximately 48.6% (4,307/8,799) of participants used an in-home treatment method to treat their tap water for drinking purposes. This study provides a broader geographic perspective and more current estimates of Canadian water consumption patterns than previous studies. The identified factors associated with daily water consumption could be beneficial for risk assessors to identify individuals who may be at greater risk of waterborne illness.

Key words | alternative water sources, bottled water, tap water, treatment devices, water consumption

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INTRODUCTION

The safety and quality of drinking water is crucial to community and individual health (McKiernan *et al.* 2008). Global climate change and various anthropogenic factors (e.g. population growth, synthetic chemical use and industrialization) continue to put increased pressures on water quality and quantity in Canada (Murdoch *et al.* 2000; Carr & Neary 2008). Internationally, there have been efforts to understand the characteristics of individuals at risk and water consumption levels (Westrell *et al.* 2006; Mons *et al.* 2007; Kyunghee *et al.* 2009) as these pressures have the potential to increase the susceptibility of drinking water to contamination from chemicals and microorganisms (Hunter *et al.* 2003; Charron *et al.* 2004; Krewski *et al.* 2004; Thomas *et al.* 2006). Throughout the world, contaminated water continues to be a cause of endemic and epidemic gastrointestinal illness (Craun *et al.* 1998; WHO 2004; Miettinen 2009). In recent years, numerous outbreaks of waterborne illness have been reported in Canada (Stirling *et al.* 2001; Hrudey *et al.* 2003; Auld *et al.* 2004; Isaac-Renton *et al.* 1994; WHO 2004; Schuster *et al.* 2005; Health Canada 2008b).

Water consumption is a multi-faceted issue; understanding how much water Canadians are drinking, its sources (e.g. tap or bottled water), and the use of in-home water treatment methods is important in assessing the risk of waterborne illness caused by chemical and microbiological hazards, as well as understanding supply and demand of specific water sources, among other issues. Until very recently, water consumption information for Canada was last gathered in the 1980s (Health & Welfare Canada 1981; Ershow & Cantor 1989). Since then, several studies have examined water consumption patterns of Canadian

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residents, but many were restricted to specific geographic locations (e.g. Craun & Calderon 2006; Jones et al. 2006a, b, 2007b; Pintar et al. 2009). Recently, however, new research investigating drinking water consumption patterns and determinants for an individual's choice has been published, highlighting the importance of nationally representative data (Dupont et al. 2010). Further assessments of water consumption patterns at the national level, such as Dupont et al. (2010) are needed in order to more accurately evaluate and identify the risk of exposure to waterborne contaminants in Canada.

In addition to tap water consumption practices, the use of alternative water sources is an emerging issue with respect to risk. Since the national studies in the 1980s, the use of bottled water and water treated with in-home treatment methods (e.g. jug, tap and fridge filters) has become more common (Levallois et al. 1998; Jones et al. 2007a; Health Canada 2008b), and has been attributed to the public perception that these water sources are of higher quality and overall safety compared with regular tap water (AWWARF 1993; Levallois et al. 1999; Lee et al. 2002; Jones et al. 2007a; Johnson 2008). Furthermore, the public perception of water plays a large role not only in the type of water individuals consume, but also in the way individuals comply with testing and provide support for policy change (Jones et al. 2006b, 2007a, unpublished; Janmaat 2007; Johnson 2008; Dupont et al. 2010). It is important to consider the consumption of alternative water sources during risk assessments, as these sources of water present different risks of exposure to waterborne contaminants for consumers (Abbaszadegan et al. 1997; Blackburn et al. 2004; Health Canada 2005; Saleh et al. 2008).

In the past nine years, seven cross-sectional, community-level surveys with drinking water assessment components were performed within specific regions of Ontario (Jones et al. 2006a, b, unpublished; Pintar et al. 2009), British Columbia (Jones et al. 2007b), and Newfoundland and Labrador (Butt 2010; Roche & Jones unpublished). The overall purpose of the present study was to pool the data from the seven studies in order to estimate Canadian drinking water consumption patterns. The specific objectives were to: (a) describe the drinking water consumption patterns of Canadians; (b) identify associations between the amount of tap water consumed per day and bottled water use, home water treatment use and demographic characteristics of the participants; and (c) compare the characteristics of tap water and non-tap water users.

METHODS

Datasets

Data from seven cross-sectional studies (2001–2007) were used in this study and are described in detail in Table 1. While the studies varied with respect to primary interest (e.g. endemic gastrointestinal disease and public perception of water quality), they all collected information pertaining to drinking water consumption patterns (tap and bottled water), the type of in-home water treatment methods used (if any) and participant demographics.

Free and informed consent of the participants or their legal representatives was obtained and the study protocol was approved by the appropriate Committees for the Protection of Human Participants, by all universities and agencies involved in the seven separate studies this paper comprises. For specific committees, university/approval agencies, approval dates and protocol numbers please refer to Table 2.

Merging the data

Prior to merging the data from the seven studies into one database, a preliminary feasibility assessment was performed to ensure that it was appropriate to combine the datasets. The original questionnaire from each study was compared to ensure questions and question wording yielded the same type of information.

While all data had been previously cleaned and coded by their respective investigators, each individual dataset was re-examined to ensure all data were entered and coded correctly. Water consumption, in-home water treatment status, and individual and household-level demographic information was imported and merged into a single Microsoft Excel spreadsheet (Microsoft® Excel 2008 for Mac (Version 12.0)). A random number generator was used to select 10% of the responses within the merged dataset. These responses were compared back to the original dataset to ensure there were no errors during the merging process.

Table 1 | Summary of the seven cross-sectional community-level studies used in the formation of the collated dataset analyzed in this study

Study	Location/study area	Date conducted	Survey type	Sample size	Response rate (%)	Reference
1	Waterloo Region, Ontario	November 2005–March 2006	Telephone survey	2,332	32.7	Pintar *et al.* (2009)
2	Hamilton Region, Ontario – Municipal water sources	May 2004	Postal survey	267	53.0	Jones *et al.* (unpublished)
3	Hamilton Region, Ontario – Private water sources	May 2004	Postal survey	246	54.7	Jones *et al.* (2006b)
4	Province of Newfoundland and Labrador – Municipal water sources	March–April 2007	Telephone survey	563[a]	25.9[a]	Butt (2010)
5	Province of Newfoundland and Labrador – Private water sources	March–April 2007	Telephone survey	618[a]	13.4[a]	Roche & Jones, (unpublished)
6	City of Hamilton, Ontario	September 2001–March 2002	Telephone survey	1,757	37.4	Jones *et al.* (2006a)
7	Vancouver, East Kootenay and Northern Interior regions of British Columbia	June 2002–June 2003	Telephone survey	3,358	44	Jones *et al.* (2007, b)

[a]Only a subset of the data used in the Newfoundland & Labrador studies were available for analysis at the time of this study; 513 of the 563 participants used by Butt 2010 were available (response rate = 20.3%), and 501 of the 618 participants used by Roche & Jones (unpublished) were available (response rate = 11.2%).

Table 2 | Summary of ethics approval information by the appropriate Committees for the Protection of Human Participants for all seven studies

Study	Ethics committee	University/approval agency	Approval date	Protocol #
1	Human Subjects Committee	University of Guelph	19 August 2005	05AU005
2	Human Subjects Committee	University of Guelph	20 January 2003	JA001
3	Human Subjects Committee	University of Guelph	20 January 2003	JA001
4	Human Investigations Committee	Memorial University of Newfoundland and Labrador	25 July 2006	06.98
5	Human Investigations Committee	Memorial University of Newfoundland and Labrador	25 July 2006	06.98
6	Human Subjects Committee & Research Ethics Board	University of Guelph & St Joseph's Hospital and McMaster University		
7	Human Subjects Committee & Behavioral Research Ethics Board	University of Guelph & University of British Columbia	1 March 2002	

(1) Waterloo Region, Ontario – municipal and private water sources; (2) Hamilton Region, Ontario – municipal water sources; (3) Hamilton Region, Ontario – private water sources; (4) Province of Newfoundland and Labrador – municipal water sources; (5) Province of Newfoundland and Labrador – private water sources; (6) City of Hamilton, Ontario – municipal and private water sources; (7) Vancouver, East Kootenay and Northern Interior Regions, British Columbia – municipal and private water sources.

Data collected

Tap water consumption

Participants were asked how many 250 ml servings of tap water they consumed, either in the previous 24-hour period (three of seven studies) or on an average day (four of seven studies). The former studies provided a detailed description to inform participants that 'tap water included plain water, as well as cold beverages (not coffee or tea) made with water, including frozen juices and crystal drink mixes', while the latter provided a more general description to inform participants that 'tap water is water directly from the tap (not treated in the home)'. All studies also provided participants with a conversion method (250 ml = 8 ounces = 1 cup/glass) and presented other measurements, including a small carton of milk and a regular sized bottle of water, in an attempt to reduce error in estimating consumption.

Three of the seven studies (7,447/8,974 participants) used an open-ended question to capture the amount of tap water consumed, while the other four studies (1,527/8,974 participants) used categories (e.g. 1 to 2.9 glasses). Thus, a new outcome variable was created to incorporate the two types of data; discrete values were assigned to each categorical observation by replacing the category range with the mean of that range (mean of range calculated using continuous observations from the 7,447 responses).

Bottled water consumption

Participants were asked in all seven studies to report their consumption of bottled water. The term 'bottled water use' or 'bottled water user' was used to refer to a participant if 75% or more of their total daily water intake consisted of bottled water.

In-home water treatment

All seven studies included questions on the use of in-home water treatment, including the specific treatment method(s) employed. Each study provided participants with a list of in-home water treatment methods to choose from, including an 'other' category if none of the options was applicable. The specific treatment methods available were: jug filter, tap filter, water softener, boiling, reverse osmosis, in-line filter, fridge filter, ultraviolet disinfection, iron removal, add chlorine/javex, ozone disinfection and candle filter. Participants were given the option to report the use of more than one treatment method, if applicable.

Demographic variables

In each of the seven studies, participants reported demographic information, including gender, age, education level, household income, and the cultural group with which they most identified. The province that each participant resided in was also recorded.

Analysis

Participants with a missing answer for a particular variable (including 'don't know' and 'refused' responses) were excluded from the analysis of that variable. All data cleaning, screening and entry were performed in Microsoft® Excel 2008 for Mac (Version 12.0). Data coding was performed in Microsoft® Excel 2008 for Mac (Version 12.0) and STATA/IC 11.0 for Mac (STATA Corporation, College Station, Texas, USA).

Participants who consumed no tap water were excluded from the multivariable analyses pertaining to tap water consumption. Non-tap water and tap water users were compared with respect to bottled water use, in-home water treatment status, and demographic variables using Pearson's chi-square test. Demographic characteristics of the study population were compared with the overall Canadian population using Pearson's chi-squared test. In both sets of chi-squared analyses, significant differences ($p < 0.05$) between subcategories for each variable were assessed using a Z-test.

Prior to statistical analysis, causal diagrams were constructed to identify anticipated direct or indirect associations between predictor variables and the outcome, as well as confounding or intervening relationships among the variables. All statistical analyses were performed with STATA/IC 11.0 for Mac (STATA Corporation, College Station, Texas, USA).

Univariable analyses

F-tests were used to assess the univariable associations between the amount of tap water consumed and age, gender, education level, household income, cultural group, province, in-home water treatment status and bottled water use. Pearson correlation coefficient analyses were performed between predictors, with a correlation coefficient of 0.8 or higher, used to indicate high correlation. In the event of two variables being highly correlated, the variable with fewer missing values was used.

Multivariable analyses

A multivariable least squares regression model was used to analyze the amount of tap water consumed daily. All variables unconditionally associated with the outcome at a significance level of 20% (Dohoo *et al.* 2009) or less were initially included in the model. A manual stepwise backward elimination procedure was used to construct the main effects model. The significance level for all final analyses was set at $p < 0.05$.

A $\log_{10}$ transformation was applied to the outcome in order to achieve the model assumptions of homoscedasticity (homogeneity of variance) and normality. Confounding was assessed at each stage of the model building process by observing a change of 30% or more in model coefficients when a variable was removed. All biologically plausible, two-level interaction terms of the final main effects were generated and tested; all significant interactions were included in the final model with their main effects. Standard residual analyses were performed to assess for a normal distribution of the standardized residuals and for homoscedasticity. Diagnostic tests and plots of residuals and influence measures were used to identify unusual values or characteristics within the model. Outliers and leverage points were assessed in the final model for unusual observations, Cook's distance was used to assess the effect of an observation on parameter estimates, difference in fit values were used to detect influential observations, and DFBETA values were used to assess the influence of observations on a specific coefficient (Dohoo *et al.* 2009).

RESULTS

Representativeness of the study population

A total of 27,426 residents were contacted and eligible for inclusion in the seven studies, of which 8,974 completed surveys; hence, the overall response rate for this study was 32.7% (8,974/27,426). Statistical comparisons between the demographic characteristics of the study population and the 2006 census data on the Canadian population (Statistics Canada 2006) are shown in Table 3. Overall, survey participants were more likely to be of North American ethnicity, female, older, university educated and have a lower household income compared with the overall Canadian population.

Descriptive results (tap and non-tap water users)

Responses for the type of drinking water consumed per day were received from 99.4% (8,916/8,974) of the participants in the study. Approximately 70.9% (6,325/8,916) consumed some tap water, while 29.1% (2,591/8,916) consumed no tap water.

Overall, approximately 24.9% (2,221/8,916) of participants were considered bottled water users (75% or more of their total daily drinking intake was bottled water), and of those participants approximately 94.1% (2,089/2,221) consumed bottled water exclusively. Approximately 5.6% (499/8,916) of study participants reported consuming no water (i.e. neither tap nor bottled).

Responses regarding in-home water treatment methods were reported by 98.0% (8,799/8,974) of the participants. Approximately 48.6% (4,307/8,799) reported the use of at least one water treatment method in their household. Of those, 12.5% (415/3,322) and 10.1% (99/985) of tap and non-tap-water-consuming participants employed the use of two treatment methods, respectively. The specific in-home water treatment methods employed by tap and non-tap water users are shown in Table 4. Jug filter use was the most common method employed by both tap and non-tap water users (55.5 and 39.9%, respectively).

Comparing tap and non-tap water users

The chi-squared analyses comparing tap water users ($n = 6,325$) and non-tap water users ($n = 2,591$) with respect to demographic factors, bottled water use and in-home water treatment are shown in Table 5. Tap and non-tap water users did not differ by gender ($X^2 = 0.06$, $p = 0.80$); however, they did significantly differ for all other variables ($p < 0.01$).

Daily volume of tap water consumed (among tap water users)

In total, 29% (2,591/8,916) of participants were excluded from the analyses pertaining to tap water consumption

Table 3 | Comparison of survey participants from Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia to the overall Canadian population (Statistics Canada 2006)

Variable		Survey participants (#)	Survey participants % ($n = 8,974$)	Canadian residents % ($n = 31,612,900$)	Chi-squared statistic
Age (years) ($p < 0.0001$)	<18	974	10.9[a]	24.4	
	18 to 29	1,042	11.6[a]	12.9	
	30 to 39	1,389	15.5[a]	13.4	
	40 to 49	1,574	17.5[a]	16.5	
	50 to 59	1,568	17.5[a]	14.1	
	60 to 69	1,081	12.0[a]	8.9	
	>70	901	10.0	9.8	
	Unknown	445	5.0		918.1
Education level ($p < 0.0001$)	Grade school	422	4.7[a]	23.5	
	Some high school	918	10.2	NA	
	High school	1,923	21.4[a]	30.9	
	College/trade school	1,828	20.4[a]	27.8	
	University	2,031	22.6[a]	11.5	
	Postgraduate	301	3.4[a]	6.4	
	Other	1,080	12.0		
	Unknown	471	5.2		3,051.0
Household income ($CAD) ($p < 0.0001$)	<$20,000	1,349	15.0[a]	7.0	
	$20,000 to $39,999	1,677	18.7	18.0	
	$40,000 to $59,999	1,167	13.0[a]	19.0	
	>$60,000	1,994	22.2[a]	56.0	
	Unknown	2,787	31.1		2,901.0
Gender ($p < 0.0001$)	Male	3,521	39.0[a]	49.0	
	Female	5,395	61.0[a]	51.0	319.5
Cultural group ($p < 0.0001$)	North American	5,738	63.9[a]	38.1	
	South American	67	0.7[a]	1.3	
	Eastern European	287	3.2[a]	11.0	
	Western European	463	5.2[a]	16.0	
	African	27	0.3[a]	1.5	
	Mediterranean	55	0.6[a]	10.0	
	South Asian	117	1.3[a]	4.8	
	Southeast Asian	338	3.8[a]	8.1	
	Arab or West Asia	49	0.5[a]	2.8	
	Australasian	9	0.1[a]	0.2	
	Native North American	63	0.7[a]	6.1	
	Other	169	1.9		
	Unknown	1,592	17.7		5,362.0

[a]Proportion in that subcategory was significantly different ($p < 0.05$) between survey and census population.

because they did not drink any tap water, resulting in a total of 6,325 tap water responses for analysis.

The daily volume of tap water consumed among tap water users ranged from 0.03 to 9.0 L, with a mean value of 1.2 L per day (Table 6). The summary statistics and unconditional analyses of the associations between the volume of tap water consumed per day and bottled water use, in-home water treatment and demographic variables are provided in Table 7.

The final multivariable model, for which a $\log_{10}$ transformation was applied to the outcome (L of water consumed per day), was significant ($F = 35.95$; $p < 0.0001$), with an adjusted R^2 value of 10.8% (Table 8). When all other variables in the model were held at their referent categories and the in-home water treatment coefficient was back-transformed from the $\log_{10}$ scale and converted from mL to L, participants that treated their tap water using an in-home water treatment method consumed 0.0013 L more

Table 4 | Types of in-home water treatment methods used for drinking water purposes, as reported by 3,322 tap and 985 non-tap water consumers in Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia

Water treatment method	Tap water consumers		Non-tap water consumers	
	Frequency	Percentage	Frequency	Percentage
Jug filter	2,075	55.5[a]	433	39.9
Tap filter	517	13.8	153	14.1
Water softener	291	7.8[a]	129	11.9
Boiling	270	7.2[a]	223	20.6
Reverse osmosis	167	4.5	60	5.6
In-line filter	119	3.2[a]	22	2.0
Fridge filter	88	2.4	21	1.9
Ultraviolet disinfection	55	1.5	9	0.8
Iron removal	30	0.8	7	0.7
Add chlorine/ javex	23	0.6	3	0.3
Ozone disinfection	4	0.1	2	0.2
Candle filter	2	0.1	1	0.1
Other	96	2.5	21	1.9
Total	3,737[b]	100	1,084[b]	100

[a]Proportion in that subcategory was significantly different ($p < 0.05$) between tap and non-tap water users.
[b]Larger than number of participants that treat tap water, as some participants used more than one treatment method.

than participants that did not ($p < 0.0001$; 95% CI [0.012, 0.014]). An interaction term between age and gender was significant ($p < 0.0001$); its association with the outcome is depicted in Figure 1. Generally, while all other variables were held constant, female participants in all age categories over the age of 29 years consumed more tap water than male participants. An interaction term between age and bottled water use was also significant ($p = 0.006$) and its association with the outcome is depicted in Figure 2. Generally, while all other variables were held constant, tap water consumption among non-bottled water users was relatively constant, regardless of age, while tap water consumption among bottled water users generally decreased with age. As expected, bottled water users consumed less tap water than non-bottled water users, regardless of age.

DISCUSSION

Daily volume of tap water consumed (among tap water users)

The daily volume of tap water consumed among participants in this study was highly variable (0.03 to 9.0 L/day), which may reflect the true variation in water consumption patterns among Canadians. Estimates of water consumption vary by study and geographic location, and previous studies have reported the mean daily volume of tap water consumption to range from 0.09 to 1.6 L (Levallois *et al.* 1998; EPA 2000; Westrell *et al.* 2006; Mons *et al.* 2007; Kyunghee *et al.* 2009).

From the final multivariate model, a significant interaction was observed between age and gender on the daily volume of tap water consumed among tap water users. For

Table 5 | Comparison of tap water users ($n = 6,325$) and non-tap water users ($n = 2,591$) for age, education level, gender, province, cultural group, bottled water use, in-home water treatment status and household income

Characteristic		Tap water users # (%)	Non-tap water users # (%)	Chi-squared statistic
Age (years) ($p < 0.0001$)	<18	655 (10.4)[a]	319 (12.3)	
	18 to 29	743 (11.7)	299 (11.5)	
	30 to 39	980 (15.5)	409 (15.8)	
	40 to 49	1,078 (17.0)[a]	496 (19.1)	
	50 to 59	1,159 (18.3)[a]	409 (15.8)	
	60 to 69	846 (13.4)[a]	235 (9.1)	
	>70	710 (11.2)[a]	191 (7.4)	
	Unknown	154 (2.4)[a]	233 (9.0)	
	Total	6,325	2,591	66.8

(*continued*)

Table 5 | continued

Characteristic		Tap water users # (%)	Non-tap water users # (%)	Chi-squared statistic
Education level ($p < 0.0001$)	Grade school	300 (4.7)	114 (4.4)	
	Some high school	612 (9.7)[a]	291 (11.2)	
	High school	1,352 (21.4)	563 (21.7)	
	College/trade school	1,292 (20.4)	532 (20.5)	
	University	1,520 (24.0)[a]	504 (19.5)	
	Postgraduate	217 (3.4)	81 (3.1)	
	Other	715 (11.3)[a]	356 (13.7)	
	Unknown	317 (5.0)	150 (5.8)	
	Total	6,325	2,591	31.5
Gender ($p = 0.8$)	Male	2,503 (39.6)	1,018 (39.3)	
	Female	3,822 (60.4)	1,573 (60.7)	
	Total	6,325	2,591	0.06
Province ($p < 0.0001$)	Ontario	3,071 (48.6)[a]	1,480 (57.1)	
	Newfoundland & Labrador	807 (12.7)[a]	203 (7.8)	
	British Columbia	2,447 (38.7)[a]	908 (35.0)	
	Total	6,325	2,591	72.3
Cultural group ($p < 0.0001$)	North American	4,103 (64.9)[a]	1,606 (62.0)	
	South American	45 (0.7)[a]	121 (4.7)	
	Eastern European	161 (2.5)[a]	149 (5.8)	
	Western European	311 (4.9)[a]	7 (0.3)	
	African	20 (0.3)[a]	19 (0.7)	
	Mediterranean	36 (0.6)[a]	38 (1.5)	
	South Asian	76 (1.2)[a]	206 (8.0)	
	Southeast Asian	131 (2.1)[a]	14 (0.5)	
	Arab or West Asia	34 (0.5)	23 (0.9)	
	Australasian	6 (0.1)[a]	21 (0.8)	
	Native North American	40 (0.6)	3 (0.1)	
	Other	85 (1.3)[a]	83 (3.2)	
	Unknown	1,277 (20.2)[a]	301 (11.6)	
	Total	6,325	2,591	211.7
Bottled water use ($p < 0.0001$)	Yes	132 (2.1)[a]	2,089 (80.6)	
	No	6,188 (97.8)[a]	499 (19.3)	
	Unknown	5 (0.1)	3 (0.1)	
	Total	6,325	2,591	6,065.0
In-home water treatment status ($p < 0.0001$)	Yes	3,322 (52.5)[a]	985 (38.0)	
	No	2,919 (46.2)[a]	1,573 (60.7)	
	Unknown	84 (1.3)	33 (1.3)	
	Total	6,325	2,591	157.4
Household income (CAD $) ($p = 0.0009$)	<$20,000	986 (15.6)[a]	358 (13.8)	
	$20,000 to $39,999	1,216 (19.2)	457 (17.6)	
	$40,000 to $59,999	779 (12.3)[a]	379 (14.6)	
	>$60,000	1,458 (23.1)[a]	527 (20.3)	
	Unknown	1,886 (29.8)[a]	870 (33.6)	
	Total	6,325	2,591	16.6

[a]Proportion in that subcategory was significantly different ($p < 0.05$) between tap and non-tap water users.

male participants, tap water consumption was highest between the ages of 18 and 29 years and significantly lower in older age categories. Similarly, female participants between the ages of 30 and 39 consumed the most tap water, while older females consumed less water. Comparing the two genders, female participants over the age of 29 years

Table 6 | Total volume of water (including tap and bottled) and total volume of tap water consumed among tap water users (L/day), as reported by residents of Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia

		Total volume of water consumed (L/day)[a] ($n = 8,908$)	Total volume of tap water consumed among tap water users (L/day) ($n = 6,325$)
Percentile (%)	1	0.0	0.1
	5	0.0	0.3
	10	0.5	0.4
	25	1.0	0.8
	50	1.3	1.0
	75	2.0	1.3
	90	2.4	2.3
	95	2.4	2.5
	99	3.3	3.5
Mean		1.4	1.2
Standard deviation		0.8	0.8

[a]Includes both tap and bottled water consumption.

consistently drank more tap water than male participants. While these findings are supported by Westrell *et al.* (2006), who observed that Swedish women have a higher intake of tap water than Swedish men, the association between gender and tap water consumption varies depending on the study. Some studies have reported no association (Levallois *et al.* 1998; Gofti-Laroche *et al.* 2001; Beaudeau *et al.* 2003), while others have reported higher tap water consumption in men than women (EPA 2000; Kyunghee *et al.* 2009; Dupont *et al.* 2010).

The association between age and tap water consumption remains similarly unclear in the literature. Some studies report that the consumption of tap water increases with age up to 40–49 years and then decreases for individuals over the age of 50 (Ershow & Cantor 1989; Beaudeau *et al.* 2003; Kyunghee *et al.* 2009), while others report that tap water consumption is greatest among the elderly (Health & Welfare Canada 1981; Roseberry & Burmaster 1991; USDA 1995; Westrell *et al.* 2006). More recently, findings have come out suggesting higher tap water consumption among older individuals in western Canada, while finding significantly lower tap water consumption among older individuals in Quebec (Dupont *et al.* 2010). Here, age and gender were associated with tap water consumption and were part of a significant interaction; therefore, they must be considered together. Owing to differences in the published literature, it is clear that the associations between tap water consumption, age and gender must be further explored in order for this information to be used effectively in risk assessments or public health surveillance initiatives.

While understanding the factors that influence an individual's consumption of water is important, the purpose of this study was not to predict consumption patterns, but to describe the tap water consumption of participants and to identify factors associated with those patterns. The adjusted-R^2 value of the model from this study was double that of the values obtained in the seven individual studies, but the final model still explains little variation in the outcome (approximately 10.8%). An individual's day-to-day water consumption is dynamic and is affected by many factors, including personal preferences, activity level, body weight and medical status (Ershow & Cantor 1989; Jones *et al.* 2006a; Mons *et al.* 2007; Pintar *et al.* 2009): variables that were not investigated in this study. For example, one participant reported consuming approximately 9 L of water in the previous 24 h; upon follow-up, to ensure the amount reported was accurate, he noted that he had been working outside all day and subsequently consumed a large volume of water. Many other participants reported consuming no water in the previous 24 h resulting in a large range of consumption values that are very specific to the time at which they filled out the survey. Therefore, the results of this study should not be used to predict tap water consumption, but rather to understand associations between the explanatory variables and the amount of tap water consumed daily.

Consumption from alternative water sources

Bottled water consumption

Among tap water users, a significant interaction was observed between age and bottled water use on the daily volume of tap water consumed. As expected, bottled water users consumed less tap water than non-bottled water users, regardless of age. The association between age, bottled water use and tap water consumption in this study may represent a type of cohort effect. Generally, older

Table 7 | Summary statistics and univariable associations between the amount of tap water consumed and age, gender, education level, in-home water treatment status, household income, province, bottled water use and cultural group, for 6,325 tap-water-consuming residents of Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia

Coefficients	Number of survey participants	Survey participants % ($n = 6,325$)	Mean consumption of water (L/day)	Standard deviation (L/day)	25th percentile	50th percentile	75th percentile
Age (years) ($p < 0.0001$)							
<18	655	10.4	1.0	0.6	0.5	1.0	1.4
18 to 29	743	11.7	1.3	0.8	0.8	1.3	1.9
30 to 39	980	15.5	1.3	0.8	0.8	1.0	1.8
40 to 49	1,078	17.0	1.2	0.8	0.5	1.0	1.5
50 to 59	1,159	18.3	1.2	0.8	0.5	1.0	1.5
60 to 69	846	13.4	1.2	0.7	0.8	1.0	1.5
>70	710	11.2	1.2	0.7	0.8	1.0	1.5
Unknown	154	2.4	1.2	3.0	0.8	1.0	1.5
Gender ($p < 0.0001$)							
Male	2,503	39.6	1.1	0.8	0.5	1.0	1.5
Female	3,822	60.4	1.3	0.8	0.8	1.0	6.3
Education level ($p = 0.055$)							
Grade school	300	4.7	1.2	0.7	0.8	1.0	1.5
Some high school	612	9.7	1.2	0.8	0.8	1.0	1.5
High school	1,352	21.4	1.2	0.8	0.6	1.0	1.5
College/trade school	1,292	20.4	1.2	0.8	0.5	1.0	1.5
University	1,520	24.0	1.2	0.8	0.8	1.0	1.5
Postgraduate	217	3.4	1.2	0.7	0.5	1.0	1.5
Other	715	11.3	1.3	0.9	0.6	1.0	1.5
Unknown	317	5.0	1.1	0.6	0.5	1.0	1.4
In-home water treatment status ($p < 0.0001$)							
Yes	3,322	52.5	1.3	0.8	0.8	1.0	1.6
No	2,919	46.2	1.1	0.7	0.8	1.0	1.6
Unknown	84	1.3	1.2	0.7	0.5	1.0	1.9
Household income ($ CAD) ($p = 0.16$)							
<$20,000	986	15.6	1.2	0.8	0.6	1.0	1.5
$20,000 to $39,999	1,216	19.2	1.1	0.7	0.6	1.0	1.5
$40,000 to $59,999	779	12.3	1.2	0.8	0.6	1.0	1.5
>$60,000	1,458	23.1	1.2	0.8	0.5	1.0	1.5
Unknown	1,886	29.8	1.2	0.8	0.8	1.0	1.6
Province ($p = 0.95$)							
Ontario	3,071	48.6	1.2	0.8	0.8	1.0	1.5
Newfoundland & Labrador	807	12.7	1.2	0.7	0.4	0.9	2.3
British Columbia	2,447	38.7	1.2	0.8	0.8	1.0	1.5

(*continued*)

Table 7 | continued

Coefficients	Number of survey participants	Survey participants % ($n = 6,325$)	Mean consumption of water (L/day)	Standard deviation (L/day)	25th percentile	50th percentile	75th percentile
Bottled water use[a] *($p < 0.0001$)*							
Yes	132	2.1	0.3	0.2	0.1	0.3	0.5
No	6,188	97.8	1.2	0.8	0.8	1.0	1.5
Unknown	5	0.0	1.1	0.8	0.4	0.9	1.4
Cultural group ($p = 0.089$)							
North American	4,103	64.9	1.2	0.8	0.8	1.0	1.5
South American	45	0.7	1.5	0.8	1.0	1.4	1.5
Eastern European	161	2.5	1.1	0.7	0.5	1.0	1.5
Western European	311	4.9	1.2	0.8	0.8	1.0	1.5
African	20	0.3	1.6	1.1	0.8	1.0	2.2
Mediterranean	36	0.6	1.1	0.6	0.7	1.0	1.5
South Asian	76	1.2	1.4	0.8	0.8	1.3	1.8
Southeast Asian	131	2.1	1.2	0.8	0.5	1.0	1.5
Arab or West Asia	34	0.5	1.2	0.7	0.8	1.0	1.5
Australasian	6	0.1	1.3	0.8	0.5	1.4	1.5
Native North American	40	0.6	1.3	0.8	0.5	1.0	2.0
Other	85	1.3	1.2	0.7	0.8	1.0	1.5
Unknown	1,277	20.2	1.2	0.7	0.4	0.9	1.4

[a]Refers to participants for whom bottled water represents 75% or more of their total daily water intake.

individuals consumed less bottled water than younger ones, which is very similar to trends observed in a recent Canadian study (Dupont *et al.* 2010). However, it might be expected that over time, as the middle-aged individuals that primarily consumed bottled water age, future trends will show higher bottled water consumption in older individuals. Similarly, future trends in young individuals may show an increase in bottled water consumption, as the consumption habits of the current middle-aged population may become instilled in their children. On the other hand, increased media reports regarding environmental degradation due to plastic waste and human ailments from the consumption of plastic by-products may deter people from consuming bottled water. Recent trends in eco-conscious consumption may also have similar effects. While it is evident from this study that bottled water consumption in Canada is common, statements regarding future consumption patterns can only be hypothesized; we suggest that bottled water consumption be periodically assessed to detect potential changes in trends.

The consumption of bottled water is also an important factor to consider from a public health perspective, as current regulations for the treatment and distribution of bottled and tap water differs (Health Canada 2005, 2008a; Department of Justice 2010). Bottled and tap water may therefore represent different risks of exposure to waterborne contaminants for consumers. Future risk assessments should make efforts to identify the use of bottled water among individuals in order to accurately estimate their risk of waterborne exposures.

In-home water treatment

The use of an in-home treatment method for drinking water was significantly associated with increased consumption of tap water among tap water consumers. Almost half of the participants in this study (both tap and non-tap water consumers) reported the use of in-home treatment methods for their tap water. Among tap water consumers exclusively, slightly more than half of the participants reported treating

Table 8 | Final linear regression model for the $\log_{10}$ transformed amount of tap water consumed (among tap water consumers) $n = 6,085$, $F(21, 6063) = 35.95$, Prob $> F < 0.0001$, Adj R-squared $= 0.1077$, Root MSE $= 0.66$

Predictor variable		Coefficient	Standard error	*t*-test	*p*-value	[95% Confidence interval]	
In-home water treatment status	No (referent)						
	Yes	0.099[a]	0.017	5.83	<0.0001	0.07[a]	0.13[a]
Gender[c]	Males (referent)						
	Females	−0.123	0.052	−2.36	0.018	−0.22	−0.02
Bottled water use[c]	Non-bottled water user (referent)						
	Bottled water user[b]	−0.682	0.271	−2.52	0.012	−1.21	−0.15
Age (years)[c]	Age <18 (referent)						
	Age (18 to 29)	0.178	0.054	3.30	<0.0001	0.07	0.28
	Age (30 to 39)	0.012	0.051	0.23	0.818	−0.08	0.11
	Age (40 to 49)	0.020	0.050	0.39	0.693	−0.08	0.12
	Age (50 to 59)	−0.046	0.490	−0.93	0.351	−0.14	0.05
	Age (60 to 69)	0.008	0.053	0.14	0.885	−0.10	0.11
	Age (>70)	−0.008	0.057	−0.15	0.882	−0.12	0.10
Interaction between gender and age ($p < 0.0001$)	Gender × Age <18 (referent)						
	Gender × Age 18–29	0.134	0.072	1.87	0.062	−0.01	0.28
	Gender × Age 30–39	0.302	0.068	4.48	<0.0001	0.17	0.44
	Gender × Age 40–49	0.248	0.067	3.73	<0.0001	0.12	0.38
	Gender × Age 50–59	0.305	0.066	4.64	<0.0001	0.18	0.43
	Gender × Age 60–69	0.250	0.070	3.57	<0.0001	0.11	0.39
	Gender × Age > 70	0.225	0.074	3.04	0.002	0.08	0.37
Interaction between bottled water use and age ($p = 0.0057$)	Bottled × Age <18 (referent)						
	Bottled × Age 18–29	−0.707	0.308	−2.30	0.022	−1.31	−0.10
	Bottled × Age 30–39	−0.480	0.303	−1.58	0.113	−1.07	0.11
	Bottled × Age 40–49	−0.894	0.295	−3.03	0.002	−1.47	−0.32
	Bottled × Age 50–59	−0.883	0.313	−2.82	0.005	−1.50	−0.27
	Bottled × Age 60–69	−1.087	0.324	−3.35	0.001	−1.72	−0.45
	Bottled × Age >70	−0.974	0.369	−2.64	0.008	−1.70	−0.25
Model constant		1.370	0.084	16.37	<0.0001	1.21	1.54

[a]Values listed here are in $\log_{10}$ scale (back transformed values reported in text).
[b]Refers to participants for whom bottled water represents 75% or more of their total daily water intake.
[c]These variables are part of significant interaction terms.

their water in the home, while just over one-third of non-tap-water-consuming participants reported treating their water in-home. Two previous Canadian studies reported the use of in-home water treatment methods in 11 and 10% of households in Quebec and Toronto (Ontario), respectively (Hudon *et al.* 1991; Auslander & Langlois 1993), and Lee *et al.* (2002) reported that 30% of households employed the use of in-home treatment methods in the USA.

The higher proportion of treatment use reported in our study compared with these other studies may be due to temporal differences in the study periods, as well as geographic location. The increased production of low-cost, readily available treatment devices may also be responsible for the higher use observed in this study (Health Canada 2008b). In addition, the marketing of these devices and their purported effects against waterborne chemical and microbiological threats may influence the public perception of tap water and result in the purchase of such devices (Petrie & Wessely 2004; Jones *et al.* 2007a). While the reasons for using an in-home treatment method were not documented in this study, an increase in tap water consumption among individuals that treat their water, compared with those that do not, could indicate a perceived increase in the quality and safety of tap water treated in the home. Several

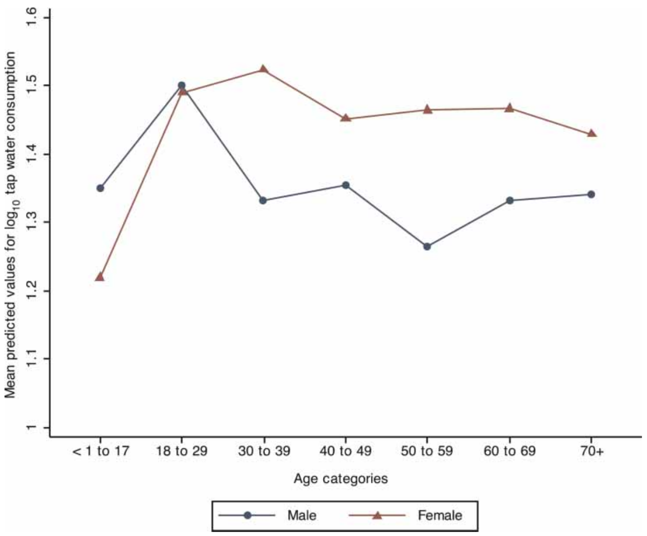

Figure 1 | The interaction effect among males and females, across all age categories, on the $\log_{10}$ transformed predicted volume of tap water consumed (while all other variables are held at their referent categories) for 6,325 tap-water-consuming residents of Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia.

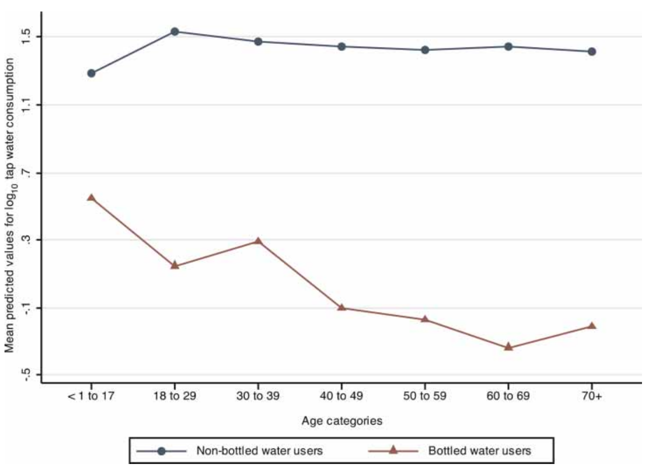

Figure 2 | The interaction effect among bottled water users* and non-users, across all age categories, on the $\log_{10}$ transformed predicted volume of tap water consumed (while all other variables are held at their referent categories) for 6,325 tap-water-consuming residents of Newfoundland and Labrador, Waterloo and Hamilton Regions, Ontario and Vancouver, East Kootenay and Northern Interior Regions, British Columbia. *The term applied when 75% or more of an individual's total daily water intake was bottled.

studies have identified reasons that influence an individual to consume water from alternative water sources, including taste, color, odor and perceived health risks (Levallois *et al.* 1999; Turgeon *et al.* 2004; Janmaat 2007; Jones *et al.* 2007a; Doria *et al.* 2009; Dupont *et al.* 2010). Water treatment in the home can alter an individual's risk of exposure to waterborne contaminants (Mintz *et al.* 1995; Clasen & Menon 2007); thus, information on the use of in-home water treatment methods is valuable in terms of public health and waterborne-disease risk assessments.

Furthermore, the specific method of in-home treatment is an important feature to consider as certain treatment devices can significantly reduce the concentration of chemicals and pathogens in the water, while others may not be so effective (Mintz *et al.* 2001; Health Canada 2008b). Approximately two-thirds of the treatment methods used by participants in this study were devices that typically use activated carbon filtration (i.e. jug and tap filters). The popular use of these types of treatment device was expected, as they are fairly inexpensive and readily available to North Americans. Although the efficacy of the specific treatment methods was not evaluated in this study, the degree of protection from microbial and chemical pathogens provided by these devices remains unclear (Pawlowicz *et al.* 2006; Clasen & Menon 2007). Thus, while consumers using such devices may feel more at ease consuming tap water, they may not necessarily be at a lower risk of exposure to waterborne contaminants. In addition, the misuse of these devices in the home may actually increase the risk of exposure to waterborne pathogens for consumers (Health Canada 2008b). Therefore, as the use of specific types of in-home treatment device has the potential to affect the risk of exposure to contaminants for consumers differently, risk assessments should also make attempts to identify the use of specific types of treatment device. A failure to account for the use of in-home water treatment methods may subsequently result in over- or under-estimations of an individual's risk of waterborne illness.

Study design

This study involved the use of a pooled analysis to assess the drinking water consumption patterns of Canadian residents. This pooled analysis is similar to a meta-analysis in that multiple studies are combined, but the pooled analysis involves the use of the raw data from the individual studies, not just the reported findings. National surveys are the preferred method to accurately identify the patterns and trends pertaining to drinking water consumption, as they provide more representative estimates of the population of interest. However, the method employed in this study is likely the next best approach, since it is cost effective, less time consuming and provides useful estimates.

As the seven studies were performed independently of one another, there were differences in certain aspects of the study design. While all seven studies took random samples of their respective sampling populations, the data collection methods were slightly different. Two of the seven studies used postal surveys to obtain participant information, while the other five studies gathered information using telephone surveys. Other than research costs and the length of the data collection period, the decision to employ either a postal survey versus a telephone survey in each study was made in order to choose the most contextually appropriate method for the study. For example, because of a lower literacy rate in Newfoundland and Labrador a telephone survey was employed. There were also differences in the style of questions asked by the investigators, which may be a source of measurement error (information bias) in this study.

As is common when pooling data from multiple studies, differences in question style (open-ended vs. categories) for reporting water consumption resulted in two types of data (continuous and categorical) for our outcome (tap water consumption). In an effort to report specific water consumption values, as opposed to a range, categorical observations were replaced with a discrete value, which was calculated using the mean of the continuous data for that range. While this method allowed specific water consumption values to be reported, it is important to note that a portion of the data included in the outcome are not specific to the individual. However, this change allowed for the inclusion of valuable water consumption data that would otherwise be removed because of inconsistencies in data type. Therefore, the pooled estimates here are reported as specific values; however, as a portion of the data consists of discrete values, our ability to generalize these findings to the target population may be affected.

Similarly, asking how much tap water a participant consumed 'in the previous 24-hour period', versus 'in an average day' may have resulted in different consumption values being reported. For example, nearly 30% of participants in this study reported that they consumed no tap water; of those participants, approximately 89% were asked: 'how much tap water did you consume in the previous 24-hour period?' It is possible some of these participants do regularly consume tap water; they just happened to consume no tap water in the previous 24-hour period. Thus, the consumption values for the participants in this study may not accurately reflect their normal water consumption habits. However, if those same participants who consume tap water regularly, but did not in the previous 24-hour period, were asked 'how much tap water do you consume in an average day?' they may have been more inclined to report a value other than zero. This latter approach is, however, heavily dependent on estimation and is not as specific as the 24-hour recall question style. Regardless of which question participants were asked, both styles of question may not identify true day-to-day variations in water consumption and, furthermore, may not reflect the usual consumption for each individual.

Different methods for collecting water consumption data have been used previously, including one- to seven-day recall periods or the use of daily water consumption diaries (Mons *et al.* 2007). Diaries allow for more accurate records of an individual's water consumption (Levallois *et al.* 1998); however, this method is more demanding of participants and investigators and may result in low response rates, as seen in a study by Levallois *et al.* (1998). In 2007, Mons *et al.* evaluated several methods for collecting water consumption data and concluded that while the diary method was the preferred method, the 24-hour recall method is the next best alternative.

As the seven studies constituting the current study were all cross-sectional in nature, it is difficult to identify whether an observed association is the result of a cohort or a period effect, and, therefore, only hypotheses regarding trends can be made. As an individual's day-to-day water consumption patterns are variable, and the trends that affect these patterns change over time, periodic follow-up to identify changing trends in water consumption patterns is recommended.

Limitations

One of the limitations of this study was that seasonal effects on daily tap water consumption were not taken into account. While the seven surveys were conducted over a wide range of dates and months, the variation in water consumption between seasons was not considered as a predictor variable in any of the studies. Most importantly, there was a lack of consumption data through the summer months, where one might expect an increase in water consumption due to warmer weather and subsequent increase in physical activity outdoors. Kyunghee *et al*. (2009) estimated a 13.4% increase in total tap water intake during the summer months in a Korean population, and Gofti-Laroche *et al*. (2001) observed a significantly higher consumption of water among French participants in the spring compared with the winter. Therefore, future studies should make efforts to collect drinking water consumption data during all months of the year to allow for changes in consumption between seasons to be assessed.

As is common with any observational study, biases may be present as a result of the survey tools employed, and different types of survey method (postal vs. telephone survey) may have differing biases. Common biases associated with the survey methods used here include non-response bias, response bias, measurement error, sampling bias and/or selection bias (Dillman 1978; de Leeuw 1992). The challenge for telephone surveys is obtaining lists of numbers and training interviewers, and requires protocols to deal with hang-ups, answering machines, invalid numbers and fax lines. The challenge for postal surveys is obtaining full mailing address information and ensuring the survey is delivered and returned appropriately (Dillman 1978). Here, we felt the potential impact of different biases associated with differing survey methods was outweighed by the fact that the different studies used the most contextually appropriate survey method for their target population.

Relatively low response rates were observed in the individual studies that formed the basis for this study. While regularly used in public health and epidemiological research, low response rates are unfortunately typical of telephone and postal surveys (Kalton & Piesse 2007). The resulting non-response bias may limit the extent to which the findings of this study can be generalized. Our survey participants were more likely to be of North American ethnicity, female, older, university educated and have a lower household income compared with the overall Canadian population. These differences were expected, as many of the individual studies observed the same trends on comparison of their study population with their target population. As certain demographic characteristics of the study populations within the individual studies were not relatively proportional to their target populations, the compilation of this data resulted in certain characteristics being over- or under-represented. This pooled analysis also involved data collected within specific regions of three Canadian provinces; however, consumption patterns and associated characteristics are missing for the other Canadian provinces. Furthermore, the locations in which the seven studies took place prevent us from obtaining a more representative sample of Canadians. Therefore, generalizing our findings to the overall Canadian population may result in an over- or under-estimation of the true day-to-day variation in tap water consumption among Canadians. Further analysis at the national level is required to fully and accurately describe the water consumption patterns of Canadian residents.

Approximately 31.1% (2,787/8,974) of participants did not provide information on household income, while 17.7% (1,592/8,974) of participants chose not to provide information on their cultural group. Unconditional associations between these variables and the amount of tap water consumed were significant, but the variables were not significant in the final multivariable model. While it is possible that household income and cultural group may not be associated with the consumption of tap water, a large proportion of missing values may have limited our ability to detect an association in the final multivariable model because of insufficient statistical power. Also, upon comparison between tap and non-tap water users, there were significant differences among household income and cultural group. Therefore, further exploration into the associations between water consumption and these specific demographic characteristics is warranted as they have the potential to facilitate the identification of individuals that may be at a higher risk of waterborne illness.

CONCLUSIONS

This study investigated the drinking water consumption patterns of residents of Canadian communities, and the factors associated with daily tap water consumption, using a pooled analysis of seven cross-sectional Canadian studies conducted between 2001 and 2007. As such, the results provide a more current understanding of drinking water consumption in Canada compared with previous reports. The mean daily volume of tap water consumed by participants was 1.2 L, ranging from 0.03 to 9.0 L/day. The volume of tap water consumed daily was associated with age, gender, bottled water use and in-home water treatment. The identification of these associations could be useful to risk assessors in identifying individuals who may be at greater risk of waterborne illness. Nearly 25% of participants consumed primarily bottled water, representing a large proportion of individuals that may have completely different risks of waterborne exposure, as they do not consume, or consume relatively little, tap water. Approximately 49% of all participants (both tap and non-tap water users) used in-home water treatment methods to treat their tap water for drinking purposes. The use of alternative water sources (bottled water and water treated in the home) was therefore common in this population. As such, it is imperative that future risk assessments and public health initiatives involve the assessment of consumption of drinking water from such alternative sources. For chemical and microbial risk assessors, understanding the various sub-groups in the Canadian population, and their respective water consumption behaviors, will help to refine risk assessments, and target appropriate interventions and education strategies for various public health initiatives.

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