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Self-reported Effects of Water on Health in First Nations Communities in Saskatchewan, Canada: Results From Community-Based Participatory Research

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ABSTRACT: Water-related health challenges on First Nations reserves in Canada have been previously documented. Our objective was to describe factors associated with self-reported health effects from tap water in 8 First Nations reserve communities in Saskatchewan, Canada. Community-based participatory approaches were used in designing and implementing cross-sectional household surveys. Individual, household, community, and contextual effects were considered in multilevel analysis. Negative health effects from tap water were reported by 28% of households (n = 579). Concerns about environmental factors affecting water quality (odds ratio [OR] = 3.4, 95% confidence interval [CI] = 1.8-6.7), rarely or never drinking tap water (OR = 2.9, 95% CI = 1.3-6.6), insufficient tap water (OR = 3.0, 95% CI = 1.4-6.3), paying for bottled water (OR = 3.2, 95% CI = 1.2-8.7), and dissatisfaction with tap water were associated with self-reported health effects (n = 393); however, the effect of dissatisfaction was modified by respondent age (P = .03). Quality and availability were associated with perceptions of health effects from drinking water, providing additional information on how ongoing concerns about drinking water influence self-reported health in some First Nations.

KEYWORDS: Drinking water, self-reported health effects, First Nations, community-based participatory research, multilevel analysis

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Introduction

Although the high number of drinking water quality advisories and water-related health challenges in First Nations reserves in Canada has been widely recognized, there has been little documented progress to date.[1,2] A 2011 assessment by Canada's federal government reported that 39% of the 571 First Nations water and sewer systems were categorized as high risk.[3] The situation has not improved much in the 20 years since a 1995 assessment by Indian and Northern Affairs Canada that found that 1 in 4 on-reserve water systems posed significant risks to the health of on-reserve First Nations residents.[1,4] For example, in October 2005, elevated levels of *Escherichia coli* in drinking water led to the evacuation of more than 1000 residents of the Kashechewan reserve in Northern Ontario, Canada.[5] First Nations also report the highest number of cases of water-related illness per capita in Canada.[6,7]

First Nations communities face a unique constitutional conundrum with respect to the regulation of their drinking water. Water safety is regulated under provincial jurisdiction; yet, the federal government is responsible for providing safe drinking water to First Nations reserves.[8,9] This political and policy challenge is part of other societal and environmental factors that have contributed to an unfavourable policy environment for water regulation and drinking water safety. The resulting problems related to drinking water availability and safety further compound the health disparities negatively affecting the people in First Nations communities.

First Nations communities have a very high number of water advisories in Canada, including the highest proportion of long-term advisories.[7] As of June 30, 2016, there were a total of 154 advisories in 114 First Nations communities across Canada, an average of 1.4 water advisories per affected community.[10,11] There are 70 First Nations reserves in the province of Saskatchewan, just more than 10% of the 617 First Nations reserves in Canada. Reserve boil water advisories in Saskatchewan account for more than 25% of all advisories in First Nations communities. This disproportionate burden of water advisories may be explained by the small population size of Saskatchewan's reserves. Saskatchewan has 66 reserves, with a total on-reserve population as reported in the 2011 Canadian census of less than 500 residents; this was the third highest number of reserves with less than 500 residents after British Columbia (298) and Ontario (81).[12] Environment Canada notes that 79% of all boil-water advisories in 2015 were issued for drinking water systems serving 500 people or less, a pattern also observed from 2010 to 2012.[13]

The problem is exacerbated by the numerous challenges small and rural communities face, including limitations of their operational capacity as a result of higher marginal service costs of the operation of their water systems and a lower revenue base.[14] In 2015, faulty equipment and process were reported for almost 78% of all boil-water advisories in Canada, with other causes including *E coli*, other microbiological parameters, and unacceptable turbidity levels at 25%.[13] Reserve populations in Saskatchewan have a variety of water treatment infrastructure ranging from new membrane-based systems, greensand, and reverse osmosis drawing from surface and groundwater sources, to private wells and no treatment facilities.

In addition to challenges communities face in maintaining water treatment facilities, other factors may also contribute to concerns about water quality and potential impacts on health. Research has shown that perception of drinking water safety is based on a combination of multiple drinking water factors, including trust in institutions providing water, knowledge of source water, distribution systems (ie, seeing rusty pipes), prior experiences with drinking water, taste, and information sources.[15] A recent review of the literature examining water and health in First Nations communities in Canada reported that despite the recognized disparities, the issue of water safety and health in Indigenous communities in Canada has had limited attention from researchers and is still poorly understood.[16] The most commonly reported health effects described in the scoping review included gastrointestinal illness, skin conditions (eczema and skin cancers), and birth defects. Differing participant worldviews and risk perceptions, frequency of reporting of illness, and variables, including housing density, record keeping, and lifestyles, potentially confounded the conclusions of many of the papers considered. Limitations in research approaches and methodologies made it difficult to draw any causal links among reported illnesses and drinking water.[16] Because of these ongoing challenges, this study sought to investigate issues related to water quality and effects of tap water on health in First Nations communities in Saskatchewan.

Our team adopted a community-based participatory research (CBPR) approach in collaboration with 8 Saskatchewan First Nations communities to gain a better understanding of the occurrence of negative self-reported health issues attributed to tap water and to identify factors associated with self-reporting negative health effects from community tap water. The CBPR approach was chosen because of its ability to connect the community directly with the research process and outcomes, as well as to enhance ethical thinking and reflection among the research team, a necessity in working with and for First Nations communities.[17,18]

Methods

Study design and data collection

Researchers worked with representatives of the Federation of Sovereign Indigenous Nations (FSIN) to establish the foundations for a CBPR approach for this project, whereby community members and researchers collaborated extensively throughout all stages of research.[19] As part of this CBPR approach, researchers adhered to the Indigenous research principles of self-determination based on ownership, control, access, and possession.[20] As a result of this partnership, and under the leadership of the FSIN, a request to participate in the study went out to First Nations communities through the FSIN and all interested communities were included in the study.[19] This study was approved by the University of Saskatchewan Behavioural Research Ethics Board (Beh#11-96). The survey was explained by the local research assistants and all participants were asked to provide verbal consent before beginning the survey. The reporting structure for this study follows the cross-sectional studies checklist for the Strengthening the Reporting of Observational Studies in Epidemiology guidelines for observational studies.[21]

The questions were designed in close collaboration with the participating communities through interviews and meetings with community leaders, as well as through the Senior Technical Advisory Group of FSIN and the Environmental Health Working Group of FSIN. Survey questionnaires were compiled, circulated, and approved by each community before use. The paper-based questionnaires were administered by community members who were provided with training and paid for their time. Each First Nations community was asked to contact as many potential survey participants as possible. Community research assistants visited individual households within the community and 1 survey was completed per household by respondents aged 18 years and older, generally during a face-to-face interview. In a few cases where respondents could not be reached, respondents completed the survey questionnaires at a later time. Completed surveys were forwarded to the University of Saskatchewan and entered in a commercial software program (Microsoft Access). Community-level data (ie, total population, affiliation with tribal council, and water system output) were obtained by phone and e-mail from the participating First Nations communities. Data collection started in June 2010 in the first community and was completed in the final community in November 2014.

Variables considered in the analysis

The outcome variable for the study was a compilation of the respondents' yes or no responses to questions about self-reported health effects to themselves or to other members of their household from the tap water that was supplied by the community. The outcome variable, self-reported health effects, was derived from a combination of 4 survey questions: (1) reported individual health concerns from drinking tap water, (2) reported household health concerns from drinking tap water, (3) reported impact of tap water on physical health, and (4) reported impact of tap water on emotional health. Negative health effects were present if the respondents indicated on any

1 of the 4 questions that they or a member of their household had a health issue. Self-reported health effects were considered absent for the analysis if the response was negative to all completed questions.

Potential risk factors at both the individual and the community levels are listed under exposure themes of interest in Tables 1 and 2, respectively. Descriptive statistics in each table include the relative frequency of the response of interest or first listed response as a proportion of the total number of people responding to the question.

The complete list of risk factors potentially available for analysis varied among communities. Indigenous communities are not homogeneous and not uniformly affected by their environment, social, and economic situations.[22] First Nations communities in Saskatchewan are also exceptionally diverse in many respects, including culturally, linguistically, socially, economically, and historically.[23] The recognition and acceptance of such diversity are essential for research activities involving policy development that will affect Indigenous peoples.[24] In consideration and with respect to this diversity and the adherence to principles of CBPR, not all individual household survey questions were included in the surveys for all communities. Individual household variables from the surveys considered in this analysis were restricted to those with comparable information that had been collected across all participating communities. Variables with more than 20% missing values were not included in the analysis. The pattern of missing values for the remaining variables was examined to assess whether it was random based on visual inspection of the results of the 'misstable' command in Stata. Given the observed pattern of missing data and the desire to make the analysis as transparent as possible for all collaborating communities, a complete case approach to data analysis was chosen rather than exploring multiple imputation methods.

Model building and data analysis

The associations between potential risk factors (Supplementary Material) and self-reported health effects were examined using generalized linear mixed models with a logit link function and a binomial distribution (Stata SE 14; StataCorp, College Station, TX, USA) and were reported as odds ratios (ORs) with 95% confidence intervals (CIs). The potential for similarity in responses within communities was accounted for using a random intercept. A null model containing only the outcome and random intercept was used to estimate the intraclass correlation coefficient (ICC) and associated baseline variability in the self-reported health outcome data among different communities.[25]

The final multivariable multilevel logistic regression analyses using individual- and community-level variables were constructed in 4 steps (Supplementary Material). The steps were as follows: assessment of the individual participant and household-level variables from the questionnaires, addition of the community-level variables, assessment of contextual effects, and assessment of potential effect modifiers.

In the first step, the analysis was restricted to individual household-level data. The unconditional/unadjusted analyses included all available data for each variable of potential interest, and all available data were used through the initial model building process (Table 1 in Supplementary Material). Because the total number of cases with complete data varied based on the variable or variables being considered (Table 1), the number of available cases was reported for each stage in the model building process (Supplementary Material).

Bivariate (unconditional) analysis was used to identify all respondent and household variables from participant questionnaires (Table 1) with $P < .20$ to be retained for the next step of the model building. Age and sex were reintroduced in the final stages of the model building process as important demographic variables and potential confounders of associations of interest. All individual variables with $P < .20$ were arranged in groups with similar exposure themes. The exposure groups included the following: demographics, water source and environment, history of water advisory, issues with water quality and quantity, water use and in-home treatment, and satisfaction with tap water (Table 1).

Where more than 1 variable within a group was retained after the unconditional analysis, backward stepwise regression was used to identify significant variables within each group before proceeding to the next step. Pairs of ordered variables within groups were first checked to see whether they were correlated using the Spearman correlation coefficient. Where $\rho > 0.9$, the variable that was most complete was retained for subsequent analysis. The final step consisted of manual stepwise (forward) entry of groups of retained exposure variables. At each step, variables with $P < .05$ were retained. At the end of this step, an iterative approach was then used to allow for variables initially removed but with $P < .20$ to be entered back into the model to ensure that none were significant or deemed a confounder. A variable was considered a confounder if adding or removing the variable from the model changed the other coefficients of interest by >20%.

In the second step, community-level variables were summarized and assessed to determine whether there was sufficient variability across communities to consider the variable in model building (Table 2). Variables for which 6 or more of the 8 participating communities had the same response were eliminated due to the associated limitation of statistical power. Bivariate (or unconditional) analyses were used to eliminate community-level variables with $P > .20$ (Supplementary Material). All community variables where $P < .20$ were entered into the existing step 1 model with the significant individual-level variables and confounders that had been identified after the first step of model building. Variables where $P > .05$ were removed from the multivariable model. Removed community-level predictors with $P < .20$ were rechecked in the resulting model to see whether they acted as confounders for other exposure outcome

Table 1. Summary of respondent and household variables considered as potential risk factors and unadjusted associations with self-reported health outcomes from 8 Saskatchewan First Nations communities (N = 579 households with 1 respondent per household).

EXPOSURE GROUP	HOUSEHOLD SURVEY RESPONSES	RELATIVE FREQUENCY	NUMERATOR[a]/ DENOMINATOR[b]	UNADJUSTED OR	95% CI	*P* VALUE
Demographics	Sex of person filling survey (male/female)[a]	0.379	195/514	1.12	(0.72–1.74)	.62
	Age of person filling survey (years)					.22
	18-34 vs ⩾55	0.282	147/522	1.65	(0.87–3.08)	.11
	35-54 vs ⩾55	0.515	269/522	1.15	(0.66–2.02)	.62
	Language first spoken was English	0.696	382/549	1.26	(0.76–2.10)	.37
	Total number of people in household (⩾6/1-5)	0.325	182/560	0.80	(0.52–1.23)	.31
	Children aged 0-5 years in household (yes/no)	0.435	252/579	1.06	(0.72–1.57)	.77
	Children aged 6-17 years in household (yes/no)	0.525	304/579	0.68	(0.46–1.01)	.06
Water source and environmental concerns	Surface water (yes/no)	0.313	173/552	0.64	(0.30–1.40)	.27
	Groundwater (yes/no)	0.674	372/552	1.28	(0.60–2.76)	.53
	Concern about environmental factors affecting water quality (yes/no)	0.366	180/492	3.91	(2.39–6.39)	<.001
	Quality of lakes (poor/OK or good)	0.435	226/520	1.09	(0.82–2.01)	.27
Water use and in-home treatment	Drink tap water rarely or never (yes/no)	0.421	238/565	6.76	(4.09–11.2)	<.001
	Boil tap water most or all the time (yes/no)	0.123	69/560	1.39	(0.77–2.49)	.27
	Filter tap water most or all the time (yes/no)	0.082	46/561	1.59	(0.77–3.28)	.22
History of water advisories	Ever experienced boil-water advisory (yes/no)	0.571	314/550	1.99	(1.29–3.08)	.002
	Ever experienced do not consume advisory (yes/no)	0.233	128/550	1.75	(1.02–3.01)	.04
	Ever experienced do not use advisory (yes/no)	0.089	49/550	2.47	(1.24–4.90)	.01
Issues with water quality and quantity	Ever experienced tap water odour (yes/no)	0.222	122/550	2.38	(1.40–4.06)	.001
	Report insufficient water (yes/no)	0.288	161/559	2.51	(1.58–3.99)	<.001
	Household bottled water cost ⩾$50/month (yes/no)	0.099	56/566	4.21	(2.21–8.02)	<.001
Satisfaction with tap water	Somewhat or very dissatisfied with tap water (yes/no)	0.206	112/545	10.90	(6.38–18.6)	<.001
	Water clarity: somewhat or very dissatisfied (yes/no)	0.154	80/519	8.55	(4.75–15.4)	<.001
	Water safety satisfaction: somewhat or very dissatisfied (yes/no)	0.203	106/522	8.82	(5.22–14.9)	<.001
	Water smell satisfaction: somewhat or very dissatisfied (yes/no)	0.247	128/519	7.22	(4.33–12.0)	<.001
	Water taste satisfaction: somewhat or very dissatisfied (yes/no)	0.238	124/520	10.20	(6.01–17.4)	<.001

Abbreviations: CI, confidence interval; OR, odds ratio.
[a]Example interpretation of the numerator for the relative frequency: the numerator is the total respondents who were male (respondents who answered the question with the first of the 2 options [from choices: male/female]), and they are reported as a proportion of the total number of respondents for that question (relative frequency of males).
[b]Denominator is the total number of respondents who answered the question.

associations of interest. The change in overall model fit was evaluated using the Akaike information criterion (AIC; Supplementary Material).

Contextual effects were evaluated in the third step (Supplementary Material). The assessment of contextual effects was considered important, given the relationships

Table 2. Summary of community-level variables considered as potential risk factors and bivariate associations with self-reported health outcomes from 8 Saskatchewan First Nations communities.

COMMUNITY ATTRIBUTES	RELATIVE FREQUENCY	CRUDE OR	95% CI	*P* VALUE
Population size on reserve (above/below median for participating communities)	4/8	0.81	(0.20–3.20)	.76
Affiliated with a tribal council (yes/no)	6/8	1.51	(0.32–7.17)	.60
Distance to urban centre (⩾70/<70 km)	3/8	0.59	(0.14–2.44)	.47
Water system output (>400/⩽400 m^3/day)	4/8	1.75	(0.45–6.77)	.42
Independent source of revenue (yes/no)	5/8	0.63	(0.15–2.54)	.51
Water treatment technology				
Magnesium greensand plant (yes/no)	5/8	1.69	(0.43–6.57)	.45
Plant age (⩾20/<20 years)	4/8	0.39	(0.11–1.37)	.14
Water system maintenance: full-time operator (yes/no)	8/8	Not evaluated		

Abbreviations: CI, confidence interval; OR, odds ratio.

among community members and resulting potential influence of prevalent community opinions on the perceptions of health. Particularly in remote communities, there is substantial likelihood of an important role for contextual factors, including community discourse and narrative, shared experiences and stories, and local politics.[26] The assessment of contextual effects in this study examined whether aggregated responses from community members for any respondent or household variables retained in the model were associated with reported health effects, after accounting for individual responses to the survey questions. For each variable retained in the final model other than age or sex, the contextual effect was the frequency of the response of interest within the community as a percentage of the total number of individuals from the community who answered the question on the original survey. Aggregate variables that represented potential contextual effects were individually sequentially entered into the existing model, and only contextual variables with $P < .05$ were retained.

In the fourth and final step (Supplementary Material), all plausible 2-way interactions were individually examined in the multivariable model for retained variables where $P < .05$. Interactions were retained if $P < .05$. For all significant interactions, relevant pairwise comparisons were estimated and the marginal predicted values were plotted for each combination of fixed effects.

The dataset was then restricted to complete cases for the variables retained in the final phase 1 model, and the modelling steps were repeated to complete the reporting process. This second phase was necessary to obtain a constant value of N and compute sequential AIC and ICCs for meaningful comparison of total variance explained among various stages of the model building process (Supplementary Material).

Pearson residuals and best linear unbiased predictors for random effects were examined and plotted against predicted values. A receiver-operator characteristic (ROC) curve was plotted and area under the curve (AOC) reported to summarize the predictive ability of the final model.

Results

Study participants and survey response rate

Eight communities participated in the questionnaire study, including representatives of 590 households with a median response of 79 households per community (range = 32-106). Of the 590 participants, 579 provided information for at least 1 of the 4 variables contributing to the assessment of self-reported health effects; the other 11 respondents did not answer any of the 4 health-related questions and were not included in the subsequent analysis.

Those responding to the questions on health effects reflected an estimated mean response rate of 32% of all households from participating communities. The median response rate across communities was 39% of households and ranged from 15% to 62%. Calculation of the denominators for response rate was based on adjusting available on-reserve population estimates for the median number of persons per household reported for each community in this survey (median = 4, interquartile range = 3-6).

Summary of self-reported health questions

Of the 579 respondents who answered at least 1 of 4 health-related questions, 162 (28.0%) described at least 1 negative self-reported health effect related to drinking tap water that was experienced by either themselves or members of their household. The proportion of people reporting at least 1 negative self-reported health effect related to tap water ranged in each of the 8 participating communities from 6.7% to 59.5% (median = 27.1%).

Not all individuals indicated the same health concerns or responded to the same number or combination of the 4

health-related questions. Of the 548 individuals who answered the first health-related question, 104 (19.0%) indicated 'Yes' to having health concerns regarding drinking the tap water supplied by their community. The second health-related question asked whether anyone in their household or visiting their home ever became ill from drinking their unfiltered tap water, and 10.5% (59 of 561) reported 'Yes'. The third and fourth questions asked how they would rate the level of impact the water in their household had on the following aspects of their health: some study participants reported negative impacts on their physical (12.1%, 61 of 504), some on their emotional health (10.5%, 52 of 497), and some on both their physical and emotional health (8.5%, 42 of 494).

Specific health effects reported in comments after 2 of the 4 questions included the following: upset or sore stomach by 37 of 579 respondents, including 5 households from 8 communities; diarrhoea by 31 households from 8 communities; general concerns about getting sick by 6 households from 5 communities; vomiting by 4 households from 1 community; and dry, itchy, or other skin irritations by 18 households from 4 communities. Although not used as a component of the primary outcome variable for health effects related to drinking water, some participants from all communities also reported negative impacts of the tap water in their household on their hygiene (9.3%, 46 of 496) and their cooking and food preparation (11.2%, 56 of 501).

Gender, age distribution, language, and household numbers for survey participants

More women participated in the survey than men (Table 1). Only 37.9% of the 514 respondents providing information on their sex were male.

Age was reported by 522 (90.2%) of the 579 survey respondents who also provided health data: 18-24 years: 9.6%; 25-34 years: 18.6%; 35-44 years: 25.9%; 45-54 years: 25.7%; 55-64 years: 14.0%; and above 65 years: 6.3%. The age distribution of self-identified First Nations people living in Saskatchewan in 2011 was calculated to match the age of those eligible to complete the survey (>18 years; Statistics Canada 2011): 18-24 years: 24.2%; 25-34 years: 23.3%; 35-44 years: 19.7%; 45-54 years: 17.2%; 55-64 years: 9.4%; and above 65 years: 6.3%.

Approximately one-third of participants (30%) who answered the health-related questions declared a language other than English as their first spoken language, sometimes in combination with English (Table 1). Approximately one-third of respondents reported living in a household of 6 persons or more (Table 1). Children aged 5 years or younger were reported in 43.5% of households and children aged 6-17 years in 52.5% of households.

Participating communities

The 8 First Nations communities involved in this study represented 11% of the 70 First Nations in the province of Saskatchewan.[12] Similarly, their total on-reserve population size of 7132 represented more than 13% of the Saskatchewan on-reserve population of 53 954 reported in the 2011 National Household Survey.[23] The average on-reserve population was 892 (standard deviation [SD] = 461). The average distance of the 8 communities relative to at least 1 of Saskatchewan's 3 major urban centres of Saskatoon, Regina, and Prince Albert was 124 km (SD = 119 km). All but 2 were affiliated with 1 of 9 tribal councils in Saskatchewan. The participating communities were of 4 ethnic groups – Cree, Saulteaux, Lakota, and Chippewa – and belonged to 3 of the 6 treaty lands in Saskatchewan.[27]

Water context of participating communities

Six of the 8 First Nations communities received their raw water from a groundwater source. One community had a surface water source, whereas a second had a municipal-type agreement to receive treated surface water from a neighbouring city. The water treatment systems of the 8 First Nations communities involved in this study represented 9% of the 99 water treatment systems in First Nations communities in the province of Saskatchewan. Of the 8 community water treatment systems, 2 were manganese greensand only, 2 were a combination of greensand and reverse osmosis, 1 was a combination of biological filtration and reverse osmosis, 1 was rapid sand, and 1 community received treated water piped from a provincially regulated system off-reserve. The final community had 2 water treatment systems with manganese greensand and reverse osmosis. The mean age of the treatment plants serving the 8 communities was 21 years (SD = 10 years). The average of the water treatment plant outputs reported by the 7 communities for which data were available was 558 m^3/day (SD = 284 m^3/day) per community and 662 m^3/year (SD = 266 m^3/day) per person assuming all persons relied on the community water system and based on reported on-reserve population. All of the treatment facilities had a dedicated plant operator.

Water was transported to community dwellings using both pipe and truck in 7 communities and truck only in 1 community. Private wells were used as the primary water source for some homes in 2 communities. Seven of the 8 communities reported outdoor cisterns and 1 community reported indoor tanks for water storage for individual households.

Drinking water source and quality reported by survey participants

Most survey respondents described having groundwater as a source for their drinking water (Table 1). In 2 communities, respondents were more likely to report surface water as their primary source (94% and 99%), whereas respondents from the remaining 6 communities were more likely to report having a groundwater source (71%-100%). Of the 37% (180 of 492) of respondents who reported concerns about something affecting

the quality of the water in their community (Table 1), 77% (139 of 180) provided comments describing reasons for their concerns. The most common themes identified included pesticides, herbicides, insecticides, or other chemicals (16.4%, 81 of 492), bacteria (9.5%, 47 of 492), heavy metals including mercury (3.7%, 18 of 492), and garbage (2.6%, 13 of 492). When asked to rate the quality of lakes, rivers, and streams located in and around their community (Table 1), 15.8% (82 of 520) reported very poor, 27.7% (144 of 520) reported poor, 40.6% (211 of 520) reported 'OK', 13.1% (68 of 520) reported good, and 2.9% (15 of 520) reported very good.

Tap water use and in-home treatment

When community members were asked whether they drink water straight from the tap when at home, 27.1% (153 of 565) reported never, 15.0% (85 of 465) reported rarely, 23.7% (134 of 565) reported most of the time, and 34.2% (193 of 520) reported always. Few households reported any type of in-home treatment, with 12.3% reporting boiling their water other than when there is a boil-water advisory and 8.2% reporting some sort of in-home filtering system for their drinking water (Table 1). Of those with an in-home treatment system, 34 households reported using some type of activated charcoal/carbon filter system or jugs, 14 households reported using distilled water, and 5 reported using reverse osmosis units.

History of water advisories

Just over half of respondents (57.1%) reported ever having a boil-water advisory while living in their community and 23.3% reported a 'do not consume' advisory (Table 1). Only 8.9% of respondents reported a total ban of the use of water in their home or a 'do not use' advisory. Within communities, the percentage of households reporting ever having had a boil-water advisory ranged from 42% to 87%. The percentage of community members reporting ever having had a 'do not consume' and 'do not use' advisories ranged from 1% to 68% and 1% to 28%, respectively.

Issues with tap water quality and quantity

Issues with strange tap water odour while living in the community were reported by 22.2% of respondents (Table 1). There was no single specific question regarding limits to tap water quantity asked across all communities; therefore, information was combined across similar questions to identify potential issues with limited access to tap water. Participants from all communities were asked whether they had ever experienced a dry well, and 6.5% (36 of 556) said 'Yes'. Participants from 4 communities were asked whether they had ever run out of water, and 50% (81 of 162) of respondents said 'Yes'. In 3 communities, respondents were asked to rate the adequacy of their access to safe drinking water during adverse drinking water conditions, and 44.9% (149 of 332) were not satisfied. Overall, at least 28.8% of participants provided at least 1 response or comment indicating they had experienced inadequate access to tap water (Table 1).

The amount spent on bottled water varied greatly, with 9.9% of participants paying more than $50 per month per household (Table 1), 8.5% (48 of 566) between $50 and $100 per month, 0.7% (4 of 566) between $100 and $150 per month, and 0.7% (4 of 566) more than $150 per month. The cost of bottled water was reported as the primary reason for drinking tap water at home by 19.3% (98 of 507) of respondents.

Satisfaction with tap water

One in 5 (20.6%) of all respondents reported being somewhat or very dissatisfied with their community-supplied tap water used for drinking purposes (Table 1). Respondents expressed dissatisfaction with the clarity (15.4%), safety (20.3%), smell (24.7%), and taste of their tap water (23.8%). The 2 most common other themes from participants who provided general comments included issues related to maintenance or cleanliness of their cisterns (n = 17) and bleach or chlorine taste or smell (n = 8).

Unconditional analyses of potential risk factors for self-reported health effects

Individual-level predictors of self-reported health effects. The unconditional associations between each potential risk factor and self-reported health effects are summarized in Table 1. None of the respondent demographic variables were unconditionally associated with self-reported health effects. Only the presence of children aged between 6 and 17 years was retained for consideration in building the multivariable model (Supplementary Material). From the variables describing source water, only 1 was unconditionally associated with reported health effects (Table 1). Respondents who reported concerns about something in the environment affecting the water quality in their community were more likely to report health concerns associated with tap water than those who did not. None of the variables describing the use of in-home treatment were associated with self-reported health effects (Table 1). However, respondents who rarely or never drank their tap water were more likely to report health concerns than those who did drink the water (Table 1).

Reporting ever having had a boil-water advisory, a 'do not use' advisory, or a 'do not consume' advisory was unconditionally associated with an increased likelihood of self-reported health effects (Table 1). Community members who identified ever having experienced a bad odour from their tap water, insufficient tap water, and paying more than $50 per month as a household for bottled water were also more likely to report health concerns related to their tap water. Similarly, participants who reported being dissatisfied with their tap water, including those not satisfied with the clarity, safety, smell, or

taste of their tap water, each had an increased unconditional likelihood of self-reported health effects (Table 1).

Community-level predictors of self-reported health effects. None of the community-level variables explored were associated with self-reported health effects in bivariate analyses (Table 2). Only the age of the water treatment plant was retained for consideration in building the multivariable model.

Final multivariable model of self-reported health effects

Of the 393 respondents who provided complete data for all of the variables included in the final model, 26.0% (102) of community members reported health effects associated with exposure to tap water (Table 3). Although this represents a loss of 186 observations from the full data set, complete case analysis was considered appropriate for these data. The pattern of missing values appeared to be random based on visual inspection. The relative frequency of each individual household risk factor considered in building the final model was also compared between the full (n = 579; Table 1) and reduced dataset (n = 393), and the absolute differences in frequency of the responses of interest between the full and reduced data were considered relatively small (median = 1.7%, maximum = 4.0%; data not shown).

During construction of the final multivariable model, the AIC improved between the null model (AIC, 404) and the final model (AIC, 311) by 23% (Supplementary Material). The ICC also dropped from 0.28 in the null model to 0.23 in the final model – a relative decrease in the unexplained variation among communities of 18%. The area under the ROC curve for the final model was 0.90 (95% CI = 0.87-0.93).

A number of individual respondent and household factors were associated with the odds of self-reporting health effects in the final multivariable model (Table 3). Respondents who were concerned that something was affecting water quality in their community were more likely to self-report health effects (OR = 3.4) than those who did not report source water concerns after accounting for all other risk factors. Similarly, participants who reported rarely or never drinking their tap water were more likely (OR = 2.9) to self-report health effects associated with tap water than those who reported drinking their tap water. Respondents who reported some indication of inadequate tap water or paying more than $50 per month for tap water were also more likely to self-report health effects related to tap water (Table 3).

The association between reporting being somewhat or very dissatisfied with tap water and the odds of self-reporting health effects related to tap water was modified by respondent age (P = .03; Figure 1; Table 3). The association between being dissatisfied with tap water and self-reporting health effects was substantially greater for respondents aged between 18 and 34 years (OR = 27.1) than for older participants (Table 4). The odds of self-reported health effects were not significantly higher for those who were dissatisfied than for those who were not for respondents aged between 35 and 54 years (OR = 2.6). However, the difference was significant for participants older than 55 years (OR = 9.0).

For respondents who were not dissatisfied with their tap water, those who were between 18 and 34 years (OR = 5.1) and those who were between 35 and 54 years (OR = 4.4) were more likely to self-report health effects than those who were 55 years or older (Table 4). However, for respondents who were dissatisfied with their tap water, those who were between 18 and 34 years were more likely to self-report health effects related to tap water than both those who were 35 to 54 years (OR = 12.0) and those who were older than 55 years (OR = 15.5).

None of the community-level variables were associated with self-reported health effects in the final model. The only variable examined was whether the plant was older than 20 years (P = .41). Similarly, none of the contextual variables examined were significant (P > .73) in the final model.

Discussion

In this study, 28% of participating reserve community members described negative health impacts from their tap water. The reported health concerns varied among individual community members and respective communities. Those who provided details on their health concerns related to drinking water most frequently described gastrointestinal illness (sore stomach, diarrhoea, and vomiting) or skin issues (pruritus). In a recent scoping review, health issues previously summarized in relation to tap water in Indigenous communities in Canada also included gastrointestinal infections, skin problems, and mental stress.[16] More recent stories of skin problems have been reported in other Canadian First Nations communities.[28,29] Our findings complement those previously reported and support the need for further investigations into health outcomes associated with drinking water and preventative measures in First Nations communities.

A number of factors associated with self-reported health effects related to tap water were identified in this study. We found that there was a strong association between individual perceptions of water quality and quantity, whether participants reported drinking the water, the amount spent per household on bottled water, and the respondents' self-reported health effects. Participants who were concerned about factors affecting the quality of their water were more likely to report health effects. Specific factors identified by survey respondents included pesticides, herbicides, insecticides or other chemicals, bacteria, heavy metals including mercury, and garbage. One recent study reported that one-third of 700 First Nations people surveyed thought their water supply was unsafe due the presence of pollutants and/or mineral content.[30] This perception suggests a concern for source water protection (SWP) among First Nations people in Canada and echoes perceptions found across the globe.[31,32]

Table 3. Final multivariable model of factors associated with the odds of self-reported health outcomes related to tap water in 8 Saskatchewan First Nations communities (N = 393 households with 1 respondent per household).

ASSOCIATION WITH SELF-REPORTED HEALTH OUTCOMES	OR	95% CI		*P* VALUE
		LOWER	UPPER	
Concern about environmental factors affecting water quality (yes/no)	3.44	1.78	6.66	<.001
Drink tap water rarely or never (yes/no)	2.94	1.32	6.55	.01
Report insufficient water (yes/no)	2.98	1.41	6.26	.004
Household bottled water cost ⩾$50/month (yes/no)	3.20	1.18	8.67	.02
Age of person filling survey (years)				.03
18-34 vs ⩾55	5.12	1.39	18.9	.01
35-54 vs ⩾55	4.39	1.35	14.3	.01
Somewhat or very dissatisfied with tap water (yes/no)	8.96	1.83	43.8	.01
Age of person filling survey (years) × Somewhat or very dissatisfied with tap water				.04
18-34 × Somewhat or very dissatisfied with tap water	3.02	0.32	28.5	.33
35-54 × Somewhat or very dissatisfied with tap water	0.29	0.05	1.88	.20
Intercept	0.01	0.00	0.05	<.001
Variance among communities	0.98	0.26	3.71	

Abbreviations: CI, confidence interval; LR, logistic regression; OR, odds ratio.
LR test vs logistic model: chibar2(1) = 19.60; Prob. ⩾ chibar2 ⩽ 0.0001.

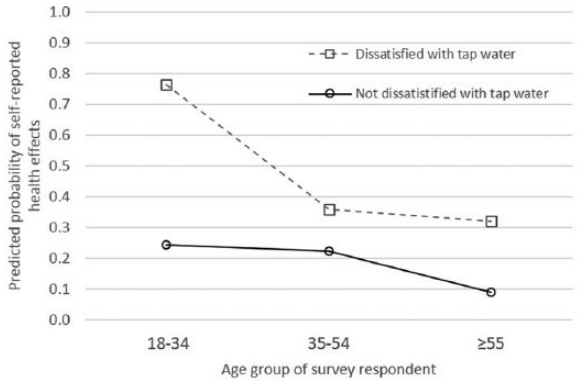

Figure 1. Summary of the marginal predicted probabilities of self-reported health effects related to tap water resulting from the interaction between dissatisfaction with tap water and respondent age in the final multivariable model of survey data collected from 8 Saskatchewan First Nations communities (N = 393 households with 1 respondent per household).

Source water protection is an important step in protecting drinking water and is recognized as one of the key barriers in the multi-barrier approach to safe drinking water adopted following the 2002 incident in Walkerton, Ontario.[33] In Canada, SWP is often applied at the watershed scale, considers multiple water uses, and is a provincially led initiative. There is a mismatch, however, between watershed and political/jurisdictional boundaries; thus, operational and implementation issues arise among provincial, federal, and First Nations governments.[34,35] First Nations boundaries do not align with the boundaries of watersheds, and First Nations fall under federal jurisdiction. Therefore, any recommendations resulting from provincially based watershed-scale SWP plans cannot be enforced on First Nations lands. In addition, First Nations SWP plans use the borders of the First Nations to define the boundaries rather than the watershed boundary; therefore, potential sources of pollution originating outside these borders are not considered or mitigated.[36] Although encouraged by the Assembly of First Nations' Environmental Stewardship Unit,[37] and in some areas, collaboration with watershed council committees has occurred,[38] more First Nations involvement in watershed-level SWP planning is needed. Active membership by First Nations in provincially based watershed-scale SWP planning may provide a step forward to alleviating concerns related to contamination of drinking water sources.

The association between never or rarely drinking water straight from the tap and increased odds of self-reported health effects might appear counterintuitive. One explanation for this may be that those who drink their tap water perceive it as safe and do not think it is causing any health effects. Those who have experienced health concerns do not drink their tap water. Directionality is difficult to assert, given the cross-sectional research design. It is not possible to easily differentiate whether drinking behaviour is affecting health or whether health concerns are influencing drinking behaviour. In a recent study of risk factors associated with the choice to drink bottled water

Table 4. Pairwise comparisons of the interaction between dissatisfaction with tap water and respondent age from the multivariable model of factors associated with self-reported health outcomes (N = 393 households with 1 respondent per household).

AGE (YEARS)	SOMEWHAT OR VERY DISSATISFIED WITH TAP WATER		AGE (YEARS)	SOMEWHAT OR VERY DISSATISFIED WITH TAP WATER	OR	95% CI		*P* VALUE
						LOWER	UPPER	
18-34	Yes	vs	18–34	No	27.1	5.16	142	<.001
35-54	Yes	vs	35–54	No	2.63	0.97	7.08	.06
⩾55	Yes	vs	⩾55	No	8.96	1.83	43.8	.01
18-34	No	vs	35–54	No	1.17	0.51	2.67	.72
18-34	No	vs	⩾55	No	5.12	1.39	18.9	.01
35-54	No	vs	⩾55	No	4.39	1.35	14.3	.01
18-34	Yes	vs	35–54	Yes	12.0	2.29	63.0	.003
18-34	Yes	vs	⩾55	Yes	15.5	2.30	104	.01
35-54	Yes	vs	⩾55	Yes	1.29	0.31	5.29	.73

Abbreviations: CI, confidence interval; OR, odds ratio.

rather than tap water in 2065 rural Saskatchewan households, those who reported tap water was not safe to drink were more likely to choose bottled water.[39] Extended study of the relationships among perceptions of water safety, choices related to drinking water, and health could contribute to improvements in water management and risk communication.

The finding that having insufficient access to tap water for drinking was associated with self-reported health concerns was supported by answers to our other survey questions where 9% of respondents reported negative impacts of the water in their household on hygiene. Unfortunately, because this was CBPR and not all community surveys were the same, there was no single question that specifically asked about whether the participants had sufficient access to tap water. This assessment used in the analysis was based on whether the participants gave any indication of inadequate access in a series of applicable questions. One question on whether the participant had ever experienced a dry well was asked on all surveys; however, individual household wells were only reported as important water supply by 2 communities. Other work suggests that providing adequate in-home water quantity enhances health, especially in northern and Indigenous communities.[40] Our findings indicate a greater need to understand the adequacy of water supply and perhaps any associated challenges and barriers to supply issues.

Households who do not use their tap water and rely on the purchase of bottled water might also be more likely to have a limited water supply due to the associated cost and inconvenience. Those households who spent more than $50 per month on bottled water were more likely to report health concerns. Spending more than $50 per month on bottled water also limits household income available for other important needs. In previous work, it was reported that 1 in 5 First Nations people living on reserve said that they use bottled water instead of tap water due to preference of taste or smell of bottled water or because they did not trust their tap water.[30]

An interesting finding from this study was the age-dependent association between being dissatisfied with drinking water and whether the survey respondent reported health effects. Respondents who were between 18 and 34 years were most likely to report health effects associated with tap water. For those who reported being dissatisfied with their tap water, those in the 18- to 34-year age group were more likely to report health effects than both those between 35 and 54 years and those older than 55 years. However, for those who were satisfied with their tap water, those between 18 and 54 years were more likely to report health effects than respondents above 55 years. The findings are very similar to Dupont et al[41] who reported that those between 18 and 24 years (OR = 4.6) and those between 25 and 54 years (OR = 2.2) were more likely to report someone had become sick from drinking tap water than those older than 55 years. This study, which assessed health risk perceptions and drinking water choices in First Nations and Non-First Nations communities, also reported a difference in risk for respondents aged between 18 and 24 years (OR = 2.1) compared with those aged between 24 and 54 years. Others have also stated that younger respondents were more likely to perceive tap water as slightly riskier[42,43] or less safe.[44] As in other studies, age is an important factor to consider when examining self-reported health outcomes.

The role of age in the wider risk perception literature remains unclear; however, it is said to be likely dependent on hazard.[15] Information about hazards associated with drinking water can be obtained from a variety of sources that are both interpersonal (family and friends) and impersonal (media). Research indicates that external information is linked to perception and that this link may be because information affects

risk perception or because risk perception leads to information searches about risk. Information leads to changes in knowledge and emotions, thus having a potential effect on the way drinking water quality and risks are perceived.[15] It may be possible that younger generations have more access to both interpersonal and impersonal information, through increased access and use of the Internet and social media, which may differentially impact their perception of drinking water.

Finally, the association between dissatisfaction with tap water and health concerns found here is also supported by a recent study exploring risk factors associated with perceptions of drinking water quality in rural Saskatchewan where there were increased odds of reporting tap water was not safe to drink if persons reported having an aesthetic complaint.[45] Educational disparities, experience with boil-water advisories, and consuming bottled water regularly can interfere with the understanding that water can have an odour and still be safe, and that health risk perceptions are increased with longer exposures to boil water advisories.[46]

Community-based participatory research has the advantage of enabling greater collaboration and mutual trust between researchers and the communities in which their research is carried out. Community members have a direct role in defining research questions that are locally and culturally relevant. It therefore strengthens community investment in the study and acceptance of the research and the findings.[47] The direct involvement of community members in collecting the data increases community capacity and the participation rates. However, this process is time-consuming and may affect the timeliness of research. The time from the start of community engagement through to analysis and reporting of the final data presented here exceeded a 5-year period. In addition, the desire for information to meet the specific needs for each community meant that a trade-off in complete comparability of all results was necessary. On reflection, the trust built in the initial years of the project through the CBPR has meant that new projects and research directions have emerged.

There were several limitations to the study design. Biases exist in the participants, research design, and researcher analyses and interpretation. Although efforts were made to reduce response bias through the use of local community coordinators and data collectors, caution is warranted when considering the self-reported health outcomes. Acquiescence, habituation, and recall biases are likely present as the survey asked participants to report on past experiences with water quality issues in communities where there have been long-standing advisories. Cultural biases may be present because the members of the research team conducting the analyses are not members of the First Nations communities. Our CBPR approach would be strengthened by including community members in the analyses and interpretation of the data. In future work analysing the qualitative data collected during the research programme, community coordinators have been invited to contribute and evaluative sharing circles are planned.

As noted in some of the findings, the cross-sectional design of this research does not clearly establish the direction of the association between the outcome variable, self-reported health effects, and the potential risk factors examined in this analysis. For most variables, there was no way to determine whether the exposure variables preceded the outcome variable. As all the questions were voluntary, there were missing data within many of the surveys for at least some of the questions. As a result, the final model contained only 393 of the original 579 observations available for analysis. Based on a visual assessment of the pattern of the missing data and a comparison of the descriptive statistics between the full and reduced data set, there was no evidence that the data were not missing at random, and therefore, the complete case analysis adopted here was considered appropriate. Although multiple imputation techniques could have been considered, the approach of directly summarizing the data provided by community members, without imputation, was considered more transparent to the participants. Finally, the participation by 8 communities limited our statistical power to investigate community-level risk factors.

Conclusions

Our results complement the numerous commissioned government reports and news stories on issues related to First Nations drinking water. Although more than a quarter of all survey participants reported some type of health concern related to their drinking water, the extent of this concern varied greatly between communities. The percentage of respondents reporting health effects varied from 6.7% to 59.5% across the 8 participating communities. Concerns about environmental factors affecting water quality, reported tap water consumption, tap water quantity, household costs of bottled water, age, and satisfaction with tap water were all important risk factors for assessing the self-reported health effects of tap water in First Nations reserve communities.

Tap water quality is among the many issues of inequality plaguing First Nations communities across Canada, which have included access to social services, education, and linguistic rights.[48–50] Raising awareness of these issues is important so that community concerns are heard and potential actions are put forward to remedy problems. Concerns about water quality and quantity and satisfaction with tap water were strongly associated with self-reported health outcomes by First Nations on-reserve residents in this study. Access to safe drinking water in First Nations communities is complicated by the legal and constitutional exigencies arising from the treaties which have had negative effects on the health of First Nations residents.[41] First Nations reserves, while located within provincial and territorial borders, are the responsibility of the federal government. It is only recently that for the territories, these responsibilities were transferred.[51,52] However, First Nations located in the provinces continue to have federal oversight of their drinking water.

As a result of the Canadian Charter of Rights and Freedoms, the Canadian Constitution, the United Nations Declaration

on the Rights of Indigenous People,[53] and international law, all people, regardless of their socioeconomic status and where they live, have a fundamental right to safe drinking water.[54] As the Standing Senate Committee on Indigenous Peoples concluded in their 2007 final report on safe drinking water, 'First Nation people in this country have a right to expect, as do all Canadians, that their drinking water is safe'.[55] However, the legal and political frameworks currently in place in Canada to oversee equitable access to safe drinking water by Indigenous people have not yet been successful in facilitating satisfactory solutions for all communities.[1,56]

Top-down approaches involving substantial investments in infrastructure, training, and monitoring have not resolved the problem to date. Partnering with communities to build understanding of local drinking water challenges and perceptions of associated health risks is necessary to better inform drinking water management and governance. Community partnerships may also lead to more locally appropriate and targeted strategies for monitoring drinking water and inform relevant education for community members in relation to drinking water risks. Policies for safe drinking water should include efforts at enhancing environmental health, such as SWP.

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Author Contributions

LAB, CLW, LM, RZ, and HTA conceived and designed the experiments; CLW, HTA, and LM analysed the data; CLW, LAB, and HTA wrote the first draft of the manuscript; RZ and LEAB contributed to the writing of the manuscript; CLW, HTA, and LAB jointly developed the structure and arguments for the paper; and LEAB, CLW, and LAB. made critical revisions and approved the final version. All authors agreed with the results and conclusions of the manuscript and also reviewed and approved the final manuscript.

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