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Water Quality and Health in Northern Canada: Stored Drinking Water and Acute Gastrointestinal Illness in Labrador Inuit

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Abstract

One of the highest self-reported incidence rates of acute gastrointestinal illness (AGI) in the global peer-reviewed literature occurs in Inuit communities in the Canadian Arctic. This high incidence of illness could be due, in part, to the consumption of contaminated water, as many Northern communities face challenges related to the quality of municipal drinking water. Furthermore, many Inuit store drinking water in containers in the home, which could increase the risk of contamination between source and point-of-use (i.e. water recontamination during storage). To examine this risk, this research characterized drinking water collection and storage practices, identified potential risk factors for water contamination between source and point-of-use, and examined possible associations between drinking water contamination and self-reported AGI in the Inuit community of Rigolet, Canada. The study included a cross-sectional census survey that captured data on types of drinking water used, household practices related to drinking water (e.g. how it was collected and stored), physical characteristics of water storage containers, and self-reported AGI. Additionally, water samples were collected from all identified drinking water containers in homes and analyzed for presence of *Escherichia coli* and total coliforms. Despite municipally-treated tap water being available in all homes, 77.6% of households had alternative sources of drinking water stored in containers, and of these containers, 25.2% tested positive for total coliforms. The use of transfer devices and water dippers (i.e. smaller bowls or measuring cups) for the collection and retrieval of water from containers were both significantly associated with increased odds of total coliform presence in stored water ($OR_{transfer\ device}$ = 3.4; 95% CI 1.2–11.7, OR_{dipper} = 13.4; 95% CI 3.8–47.1). Twenty-eight day period prevalence of self-reported AGI during the month before the survey was 17.2% (95% CI 13.0-22.5%), which yielded an annual incidence rate of 2.4 cases per person per year (95% CI 1.8 – 3.1); no water-related risk factors were significantly associated with AGI. Considering the high prevalence of, and risk factors associated with, indicator bacteria in drinking water stored in containers, potential exposure to waterborne pathogens may be minimized through interventions at the household level.

Keywords: Indigenous; drinking water; waterborne disease; point-of-use; coliforms; recontamination

Introduction

Despite progress in recent years, access to safe and reliable sources of drinking water continues to be a global issue (Hennessy and Bressler 2016), and a problem which is not restricted to developing nations. Indeed, a high overall level of service for water and sanitation infrastructure exists in developed nations (Statistics Canada 2013a; Hennessy and Bressler 2016); however, some smaller subpopulations still experience lower levels of service and water quality challenges (Bradford et al. 2016; Hennessy and Bressler 2016). Frequently, remotely located communities experience challenges related to water infrastructure and water quality and quantity (Dunn et al. 2014; Hennessy and Bressler 2016; Instanes et al. 2016). In Canada, the United States, and Australia, rural and remote Indigenous communities often face disproportionately more drinking water challenges compared to non-Indigenous populations in the same country (Bailie et al. 2004; Eichelberger 2010; Bradford et al. 2016; Hennessy and Bressler 2016).

Canadian Inuit, along with First Nations and Métis, are three constitutionally recognized Indigenous groups in Canada. In Canada's First Nations communities, 39% of the water systems are considered "high risk", and First Nations communities have 2.5 times more boil water advisories (BWAs) than non-First Nations communities (Eggertson 2006; Patrick 2011; Spence and Walters 2012; Dupont et al. 2014). Furthermore, while BWAs are meant to be a temporary measure to protect public health, many Indigenous populations face frequent or long-standing BWAs: between 1995 and 2007, Health Canada reported that the average duration of a BWA in First Nations communities was 343 days (Health Canada 2009), although some communities have faced advisories lasting over 15 years (Health Canada 2016). These issues contribute to public mistrust of municipal water and high rates of bottled water use in many Indigenous communities (Dupont et al. 2014). Inuit populations in the Canadian Arctic face similar issues with water infrastructure, water security, municipal water treatment, and BWAs (Newfoundland and Labrador Department of Environment and Conservation; Bradford et al. 2016; Medeiros et al. 2016). According to Statistics Canada, close to 40% of all Inuit adults in Canada felt their drinking water was contaminated at certain times of the year, and 15% felt that their water at home was unsafe for consumption in 2006 (Statistics Canada 2010). Other research has corroborated these concerns, with one study in northern Québec finding more than 30% of drinking water samples to have unacceptable levels of indicator bacteria (Martin et al. 2007), and another study in Northern Labrador finding that tap water often did not meet national water quality guidelines in one Inuit community (Harper et al. 2011).

While water challenges in Indigenous populations remain under-researched (Bradford et al. 2016), it is clear that Canadian Indigenous communities often experience a disproportionate burden of water-associated issues compared to non-Indigenous Canadians (Health Canada 2009; Patrick 2011; Dunn et al. 2014; Dupont et al. 2014; Bradford et al. 2016; Hennessy and Bressler 2016), and these difficulties could present a greater risk of water-related illness. For instance, high rates of shigellosis and giardiasis have also been cited as possible health consequences of poor water quality in First Nations communities (Metcalfe et al. 2011; Patrick 2011). In Arctic regions, compromised access to safe quantities and quality of water has been associated with skin and soft tissue infections, pneumonia, and influenza in Alaska Natives (Hennessy et al. 2008). In the Territory of Nunavut (one of four Canadian Inuit settled Land Claim areas), larger communities such as Iqaluit and Rankin Inlet have utilidor systems and are less susceptible to water shortages (Medeiros et al. 2016); however, some smaller communities rely on trucked water service, which can discourage water use due to potential limits in supply (Daley et al.

2014); indeed, per capita water usage in one Nunavut community was approximately three times lower than the Canadian national average (Daley et al. 2015), which could increase the risk of hygiene-related diseases (Hennessy and Bressler 2016). Other studies have shown that some Inuit populations experience some of the highest rates of self-reported acute gastrointestinal illness (AGI) in the global peer-reviewed literature (Harper et al. 2011; Harper et al. 2015a; Harper et al. 2015b), with water identified as an important risk factor for enteric illness in Canada's North (Harper et al. 2011; Pardhan-Ali et al. 2012a; Pardhan-Ali et al. 2012b; Harper et al. 2015a; Harper et al. 2015b). These issues may be further magnified as climate change and warming temperatures impact the Arctic environment (Ford 2012; Prowse et al. 2015). However, studying the proportion of illness attributable to poor water quality and quantity remains challenging. For instance, examining the extent to which waterborne pathogens contribute to AGI is difficult, as AGI-causing organisms can also be contracted through other exposure routes, such as food, contact with animals, or person-person contact (Health Canada 2011).

Most research in Indigenous communities has focused on the quality of municipally-treated tap water or untreated raw drinking water (Bernier et al. 2009; Harper et al. 2011; Goldhar et al. 2013; Dupont et al. 2014). Less research has examined microbiological recontamination of water between the source and point-of-use (Martin et al. 2007; Bernier et al. 2009). Multiple studies in developed and developing countries have shown contamination of stored water to be a public health concern (Clasen and Bastable 2003; Wright et al. 2004; Hoque et al. 2006; Oswald et al. 2007; Rufener et al. 2010; Mellor et al. 2013). Examining the health implications of water contamination between source and point-of-use is particularly relevant and important in remote northern communities, as residents often collect untreated surface water for drinking and store it in containers for later consumption (Marino et al. 2009; Goldhar et al.

2013); however, this research in Indigenous communities is rare. The goal of this research, therefore, was to understand household stored drinking water contamination and practices, and their potential associations with self-reported AGI in the Inuit community of Rigolet, Canada. Specifically, the research objectives were to describe drinking water collection and storage practices, identify potential risk factors associated with water contamination between source and point-of-use, and examine possible associations between drinking water contamination and self-reported AGI. The results are intended to inform sustainable water-related interventions, whilst developing local capacity to understand potential risk factors for waterborne illness in Northern Canada.

Methods

Study location

Approximately 60 000 Inuit live in Canada (Statistics Canada 2015), with the majority residing in the northern regions of the country, in an expanse of land and water referred to as Inuit Nunangat. This area stretches from Labrador through the Yukon Territory, and currently includes the four settled Land Claim Areas of Nunatsiavut (Labrador), Nunavik (Québec), Nunavut, and the Inuvialuit region (Northwest Territories/Yukon) (Fig. 1), plus additional Land Claim Areas that Inuit are currently negotiating with the government. Many Inuit in these regions continue to partake in aspects of a subsistence lifestyle that relies heavily on the land, sea, and ice. Activities such as hunting, fishing, trapping, and gathering of food and water are part of daily life for many Inuit in Canada, and the continuation of these cultural activities are vital to the health and wellbeing of these communities (Cunsolo Willox et al. 2012).

This study was conducted in collaboration with the Inuit community of Rigolet in the Nunatsiavut Land Claim Area, which is located along the northeast coast of Labrador, Canada

(Fig. 1). Meaning "Our Beautiful Land" in Inuttitut, Nunatsiavut is a self-governed region established in 2005 (Nunatsiavut Government 2016). The Nunatsiavut Land Claim Area is composed of five communities (from south to north): Rigolet, Makkovik, Postville, Hopedale, and Nain. These communities are remote; only accessible by air in the winter, or additionally, by boat in the summer months. There are no ice roads or groomed trails connecting communities. In 2011, Rigolet had a population of 306 residents (Statistics Canada 2012), with 85% of individuals self-identifying as Inuit; the number of males and females was approximately equal, and 21.3% of the population was under the age of 18 (Statistics Canada 2013b).

Rigolet is serviced by an underground piped water system, which delivers municipally treated tap water to all households. The source water, obtained from a local lake (i.e. surface water), is chlorinated. In January of 2014, a potable water dispensing unit (PWDU) was constructed in the community; PWDUs have been constructed in several Labrador communities as part of the Government of Newfoundland and Labrador's *Drinking Water safety Initiative,* which aims to assist small communities with demonstrated high risk water quality issues (Government of Newfoundland and Labrador Department of Municipal Affairs 2017). While the provincial government provides the PWDU, the municipal government is responsible for running costs and maintenance. These municipal water systems apply multiple treatments to water, including sand filtration, ozonation, carbon filtration, reverse osmosis, and ultraviolet light. Identical units have been installed in the communities of Makkovik, Postville, and Cartwright, and a comparable system was also constructed in Black Tickle-Domino, Labrador (Hanrahan 2014). If residents choose to drink water from the PWDU instead of tap water, they must collect water from this unit, which is housed in a public facility, and then store this PWDU water in personal containers for later consumption. Finally, some residents drink untreated brook water

(Fig. 2); this water is collected and stored in personal containers (Martin et al. 2007; Goldhar et al. 2014). Water plays a vital role in many Indigenous cultures, and consumption of brook water may be related to culturally rooted preferences for natural sources of fresh water, traditional ecological knowledge, or necessity when travelling on the land, when other sources of treated water are not available (Martin et al. 2007; Goldhar et al. 2014; Medeiros et al. 2016).

Research approach

This study is premised on a community-identified research question, with data collection, results interpretation, and knowledge mobilization conducted in partnership with local Inuit community members and governments. An EcoHealth approach guided the research process that emphasized transdisciplinary, community-based, participatory, and systems-thinking research methods (Charron 2012).

Data collection

A cross-sectional study, comprised of a questionnaire and water sampling, was conducted in Rigolet between June 23rd and June 30th, 2014. Cross-sectional study designs are useful for generating and testing hypotheses, and are suitable when attempting to explore a variety of potential risk factors and outcomes (Dohoo et al. 2012). A census survey was attempted, meaning that every individual present in the community during the study period was invited to participate directly or by proxy (children under 12 years of age). Water samples were collected from all drinking water storage containers, and questionnaires were administered in the homes of the participants.

Questionnaires

A transdisciplinary team of epidemiologists, engineers, and local Inuit researchers co-developed and administered the electronic questionnaires on iPads (Apple Inc., Cupertino, CA, USA), which were modified from a prior burden of acute gastrointestinal illness study led by the Rigolet Inuit Community Government (Harper et al. 2015a). The questionnaire was extensively pre-tested for clarity and content, and was divided into two sections: the first section was completed by all participants, or by an adult proxy in the household (i.e. a parent or main caregiver), and contained questions concerning AGI and individual drinking water habits and preferences; the second section was completed by one individual per household and contained questions regarding water storage containers in the home and potential household-level risk factors for contamination (Table 1). All questionnaires were completed in English, although translation to Inuttitut was available if requested.

The AGI case definition was consistent with previous surveys in Rigolet (Harper et al. 2015a), the Canadian National Studies on Acute Gastrointestinal Illness (Thomas et al. 2008), and several international studies (Jones et al. 2007; Adlam et al. 2011). AGI was defined as any self-reported vomiting or diarrhea (i.e. loose stool) experienced in the last 28 days not attributed to pregnancy, medication/alcohol/drug use, or diagnosed chronic conditions (e.g. irritable bowel syndrome, Crohn's disease, gastritis or ulcers from *H. pylori* infection, and/or diverticulitis) (Thomas et al. 2008). If an individual experienced more than one episode of AGI during the recall period, they were asked to describe only the most recent occurrence. Cases were categorized as mild, moderate, or severe based on criteria described by Majowicz et al. (2006).

In the questionnaire, drinking water was defined as plain unboiled water, or cold drinks made with unboiled water (e.g. frozen juice concentrate and crystal drink mixes). Questions were asked about each drinking water storage container identified within a household. Information was captured on water-handling practices for each container, including the sources of water (e.g. PWDU, brook location), location of storage, container cleaning practices, and if transfer devices or dippers were used (transfer devices refer to tools used during collection of water from the source, and dipper is a local term used for a smaller bowl or measuring cup used to retrieve water from a container for drinking). Physical characteristics of containers were also noted, such as size and material (Table 1, Online Resource 1).

Water sampling and testing

At the time of the questionnaire, water samples were taken from every drinking water storage container in each house, as well as from tap water if one or more individuals in the household identified it as a source of drinking water. Samples were drawn and dispensed into 100mL sterile bottles according to how the resident would obtain water for consumption (e.g. using the dipper if it was normally used to draw water from a larger bucket or dispensing water directly from a water cooler). Samples were processed using IDEXX Colilert® following the manufacturer's instructions to detect presence/absence of total coliforms and *E. coli* (IDEXX Laboratories 2015).

Ethics and consent

The research protocol was approved by the Nunatsiavut Government Research Advisory Committee and the University of Guelph Research Ethics Board. Written informed consent was obtained from all participants; for individuals 12-18 years of age parental permission was required, and a proxy respondent was used for children under 12 years of age. A small honorarium was offered to each household for participating in the survey; this compensation was determined through consultation with local Inuit researchers.

Data analysis

Participants who responded 'refuse to answer' or 'unsure' were excluded from the analysis of that question. Two-sample tests of proportions were used to evaluate differences in demographic data between the June 2014 survey, and 2011 Census data from Rigolet. Prevalence, estimated annual incidence rate, and incidence proportion of AGI were calculated using formulas presented in Appendix A (Rothman and Greenland 1998).

Two models were built; the first model examined the presence / absence of total coliforms in household stored water containers as the outcome variable, and the second model examined the presence / absence of self-reported AGI during the previous 28-days as the outcome variable. All independent variables underwent univariable logistic regression analysis to explore unconditional associations with each outcome variable. In order to reduce the number of explanatory variables offered to a multivariable model, variables with a p-value ≤ 0.2 in the univariable regressions were considered in multivariable analysis, which was conducted using a manual backwards stepwise model-building approach (Dohoo et al. 2012). A significance level of $\alpha \leq 0.05$ and 95% confidence intervals (i.e. $p<0.05$) were used to assess statistical significance in the multivariable models. Linearity of continuous variables with the log odds of the outcome was assessed using locally weighted scatterplot smoothing (lowess curves), and if the relationship was not linear, the variable was categorized based on biologically-plausible cut-points or trends in the lowess curve (Dohoo et al. 2012). Collinearity of independent variables was assessed using Spearman's rank correlation, using a cut-off of $|0.7|$ to classify variables as collinear. If two independent variables were deemed collinear, the more proximal independent variable with greatest biological plausibility was considered in the model building (Dohoo et al. 2012). Likelihood ratio tests were performed after the removal or addition of each variable to assess whether the full and reduced models were significantly different. Additionally, we assessed Akaike Information Criterion (AIC) in each step to confirm that the fit of the model improved as variables were removed. Confounding was also assessed at each step in the backwards selection process; if removal of a variable resulted in a 30% or greater change in regression model coefficients, the variable was considered a confounder and remained in the model regardless of its statistical significance.(Dohoo et al. 2012) Two-way interactions were tested with biologically plausible variables, as well as all variables that had a p-value ≤0.05 in univariable analysis. For the model examining AGI as the outcome variable, mixed logistic regression models were built to examine whether significant clustering of the outcome occurred at the household level (i.e. examining household as a random effect, and comparing the mixed model to a regular logistic regression model using a likelihood ratio test). Fit of the models was assessed using Pearson and Deviance χ^2 goodness-of-fit tests. Lastly, we visually explored how well the models fit the data through plotting predicted values, residuals, deviance, standardized residuals, leverage, delta beta, delta deviance, and delta χ^2; this allowed us to examine outliers and covariate patterns with high leverage. Data were cleaned and analyzed using Stata I/C 13.1 (StataCorp LP, College Station, TX, USA) for Mac.

Results

Response rate and participant demographics

A total of 275 people in 105 households were present in Rigolet during the survey period. Of those, 246 agreed to participate from 98 households, resulting in an individual response rate of 89.4% (i.e. 246/275) and a household response rate of 93.3% (i.e. 98/105). Using a two sample test of proportions, the 10-14 year age group was significantly over-represented, and the 20-24 year old age group was significantly underrepresented in our 2014 survey compared to the 2011 Canadian Census data for Rigolet (Statistics Canada 2012) (Table 2).

Drinking water sources and water-related practices

Water from the PWDU was the most frequently used source of drinking water in the community, consumed as a primary (i.e. most commonly used water source) or secondary (i.e. another water source used, apart from the primary source) water source by 74.8% of respondents (Fig. 3). While most sources of water were typically rated as “good” or “very good,” tap water had the highest proportion of “fair,” “poor,” and “very poor” ratings of perceived quality (Fig. 4).

Nearly 80% of households had drinking water stored in containers at the time of the survey. Many different types and sizes of containers were used to store water, including wide-mouthed buckets and narrow-mouthed jugs, although almost all were plastic (98.1%; Fig. 2). Approximately equal numbers of respondents stored water inside and outside of the refrigerator. Frequency of container cleaning was low; 67.0% of sampled containers were cleaned once per month or less; and 43.0% of containers had never been cleaned. Of containers that had been cleaned, the most common method was soap and water (36.0%), followed by using the rinsing nozzle located inside the PWDU filling station (15.0%), which sprays water inside of the containers (Table 3).

Coliforms in drinking water

There were 76 houses with water storage containers; water samples from 104 water storage containers in these 76 houses were obtained. There were 21 households who reported drinking tap water; 22 tap water samples were collected from these 21 households, as well as at the local school. Total coliforms were detected in 25.2% of samples from water storage containers, and in 18.2% of tap water samples. Of samples positive for total coliforms, one stored water sample and one tap water sample tested positive for presence of *E. coli*. In the final multivariable model, the use of a dipper and transfer device was significantly associated with the presence of total coliforms in stored water samples (OR_{dipper} = 13.4; 95% CI 3.8–47.1 & $OR_{transfer\ device}$ = 3.4; 95% CI 1.2–11.7) (Fig. 5, Appendix B). No significant interaction terms were identified, and the model fit the data well.

Acute gastrointestinal illness

A total of 46 people reported symptoms of AGI in the 28-day recall period. Four individuals reported symptoms of AGI but were excluded due to conditions or medications that they believed had caused their symptoms; therefore, 42 individuals met the case definition for AGI and the 28-day period prevalence was 17.2% (95% CI 13.0–22.5%). Of those who met the case definition, the proportion of mild, moderate, and severe cases were 47.6%, 23.8%, and 28.6%, respectively. The estimated annual incidence of self-reported AGI was 2.4 episodes per person per year (95% CI 1.8 – 3.1) and the annual incidence proportion was 91.3%. While many water-related variables had a positive association with AGI, no variables were significantly associated with AGI at the α=0.05 level in univariable or multivariable analysis (Fig. 5, Online Resource 2).

Discussion

The PWDU represented a new drinking water source in Rigolet in 2014, requiring residents to collect water and store it in personal containers for later consumption. Although treated tap water was available in all households, the majority of people chose to consume water from the PWDU, and most households had water stored in containers at the time of the survey.

The high consumption of PWDU water, despite its reduced convenience compared to piped tap water, may be due to several reasons. First, previous research has documented lack of trust and a dislike of municipally-supplied tap water in Rigolet (Goldhar et al. 2013), which could explain the low tap water consumption documented in this study. Second, the high PWDU usage could be due to a perception that water collection and storage are not perceived as inconvenient tasks in this community. Centralized piped drinking water infrastructure is a relatively recent amenity in Rigolet: some buildings were first serviced with tap water as late as the 1990s, and before this time, collecting water from a location outside of the home and storing it in personal containers was common-practice (personal communication, R. Shiwak, 2016). Furthermore, opting to gather water may be a choice that reflects Inuit lifestyles and culture, in which subsistence activities are an integral part of daily life that provide sustenance, connection to the local environment, and reinforce important sharing networks and values (e.g. through collecting and sharing water with family, neighbours, or Elders) (Wenzel 2000).

Total coliforms were detected in several tap water samples, and a substantial proportion of stored water containers, and this finding could indicate that water contamination occurred between source and point-of-use. Water recontamination after treatment is particularly relevant in Rigolet since the implementation of the PWDU, as residents are required to store this water in personal containers. Multiple international studies have shown that coliforms may re-enter stored drinking water through contact with hands or dippers when individuals retrieve water from wide-necked containers, such as buckets (Wright et al. 2004; Trevett et al. 2005; Mellor et al. 2013; Schriewer et al. 2015). Indeed, dippers and transfer devices were associated with significantly increased odds of total coliform present in water containers in this study. Container material and the use of lids to cover storage vessels have also been implicated as risk factors for contamination between source and point-of-use (Wright et al. 2004); these were not associated with coliform presence in Rigolet, potentially because almost all containers were plastic and had lids, resulting in very little variation in the data. Unwashed containers can also be a source of water recontamination (Wright et al. 2004), as biofilms can grow on container walls and transfer microbial contaminants into clean water when it is collected (Jagals et al. 2003). Although a significant association between cleaning practices and coliform presence was not identified in this study, survey participants reported infrequent cleaning of storage containers. A similar observation regarding cleaning of personal water storage containers in Nunavik was made by Martin et al. (2007). Moreover, water collected from the PWDU may be particularly vulnerable to recontamination from dippers or unwashed containers, as the PWDU removes residual chlorine from the municipal water. Chlorine residuals in drinking water are important in ensuring that the water is safe until consumption, as the chlorine inactivates microbial contaminants that re-enter the water between source and point-of-use (Health Canada 2006). Given the vulnerability of stored water to recontamination and the low frequency of container cleaning found in this study, a public health campaign to disseminate research findings was carried out in the community, in collaboration with local governments. As per the EcoHealth approach (Charron 2012), this campaign was developed emphasizing the pillar of knowledge-to-action, and in its design and implementation considered the cultural importance and nuances surrounding drinking water in the community. This campaign was also based on the precautionary principle, which states that where there is risk of negative impacts, cost-effective precautionary measures are justified despite a lack of scientific certainty (Environment Canada 2010). Infographics with action-oriented information on how to keep stored water clean were distributed in the community, including in the PWDU station. Additionally, each household was given stickers containing information for preparing and using a bleach solution to clean water storage containers, which could be put on containers to serve as a reminder to clean them regularly.

It is important to note that most coliforms are not dangerous to human health; however, they are frequently used in water testing to indicate presence of other harmful fecal pathogens (such as *Giardia, Cryptosporidium*, enterotoxigenic *E. coli*, or other waterborne agents that can cause AGI) (Yates 2007). Some studies, however, dispute the efficacy of using coliforms as an indicator of fecal contamination (Yates 2007; Lin and Ganesh 2013; Gruber et al. 2014), as they are not exclusive to feces and may not accurately predict presence of some types of pathogens in water (Health Canada 2012). As such, future research should prospectively sample source water to ascertain if it is free of microbial contaminants before collection, in order to confirm that contamination is occurring between source and point-of-use. Furthermore, the finding of coliforms in some tap samples warrants further investigation; collecting more detailed data and samples of tap water would be useful for obtaining a better understanding of this water source. Considering the limitations of using coliforms, it would be useful in future studies to test for specific pathogens, including enteric bacteria, parasites, and viruses, in order to examine specific AGI-causing organisms that may be present in stored water.

The estimated annual incidence rate of AGI, 2.4 cases per person per year, represents a substantial burden of illness in the community. This rate of AGI is comparable with past research in the Canadian Arctic (Harper et al. 2011; Harper et al. 2015a; Harper et al. 2015b), and is 2-6 times higher than in more southern, non-Indigenous populations in Canada (Majowicz et al. 2006; Thomas et al. 2006a; Sargeant et al. 2008; Thomas et al. 2008) and other countries (Hall et al. 2006; Jones et al. 2007; Prieto et al. 2009; Ho et al. 2010; Adlam et al. 2011; Doorduyn et al. 2012; Müller et al. 2012). No water-related risk factors were significantly associated with AGI in this study. Similarly, other international studies have failed to associate drinking water with gastrointestinal illness, despite finding high levels of microbial contaminants in stored water (Kirchhoff et al. 1985; Roberts et al. 2001; Pickering et al. 2010). This finding could indicate that water sources were not a risk factor for AGI during the study period. Indeed, there are many sources of AGI-causing pathogens, and water is only one route of exposure. Contaminated food, zoonotic transmission, or contact with an infected individual are also potential sources of AGI (World Health Organization 2011), and may play important roles in this context. Additional research assessing other potential transmission routes may prove valuable in furthering our understanding of unique risk factors for AGI in Inuit. An alternative explanation for the lack of association between drinking water and AGI in our study could be related to temporal limitations of cross-sectional studies; that is, a respondent could have developed AGI from contaminated water, but cleaned and/or refilled the water container before a water sample was collected in this study, thereby resulting in a negative test for total coliforms. Given the findings from this study, precautionary measures, such as the public health campaign implemented in the community, could serve to minimize risk of exposure to AGI-causing organisms. Follow-up work to assess the effectiveness of this campaign could be beneficial to understanding its impact on stored water contamination.

This study contributes to the limited literature that exists on drinking water and health research in Indigenous communities (Bradford et al. 2016). Several limitations should be considered. Firstly, data were collected over a short period in June 2014, and it is possible that drinking water sources, storage practices, and the incidence rate of AGI varies by season. Therefore, these results may be an over- or underrepresentation of the incidence rate of AGI at other times of year. This study design precluded establishing a temporal sequence between exposures and outcomes; this is a limitation of cross-sectional studies generally, therefore, results should not be taken to imply cause and effect. The associations evaluated in this study may be further investigated using a prospective study design. Second, the health outcome in this study was self-reported, and this leads to potential issues with misclassification, recall limitations, and reporting biases. It is possible that undiagnosed chronic AGI cases were misclassified as acute AGI or vice versa. However, any biases impacting the frequency or incidence rate of AGI in this study likely affected other burden of AGI studies in a similar manner, as the same criteria were used to define cases. Third, although this was a census survey with a high response rate, the total number of observations was fairly small (n=246), and this may have limited the ability to detect significant associations between risk factors and outcomes due to low statistical power, when a true association could exist. Moreover, there are a variety of methods available to handle missing data. Similar to other AGI studies in Canada (Thomas et al. 2006b; Harper et al. 2015a), when participants answered “unsure” or “refuse to answer” for a question, we omitted them from the analysis of this question. We acknowledge, however, that this method can result in a skewed distribution when data from different people are used in different analyses. Lastly, this research was only carried out in Rigolet, and so extrapolation of the results to other populations should be done with caution. Nonetheless, several other communities in Labrador have a PWDU, and many Alaskan villages are served by comparable systems, which require residents to collect and store water within the household (Thomas et al. 2013) These communities may experience similar issues with water contamination between source and point-of-use; this research, therefore, may resonate with, and have implications for Arctic communities across North America.

Conclusions

We assessed potential water-related risk factors for water contamination between source and point-of-use, as well as self-reported AGI in the Inuit community of Rigolet. The use of dippers and transfer devices were significantly associated with increased odds of total coliform presence in stored water. Many water-related variables had a positive association with AGI; however, no statistically significant water-related risk factors were associated with AGI in June 2014. Considering the high prevalence of, and risk factors associated with, indicator bacteria in drinking water stored in containers, a simple public health campaign on the importance of cleaning containers and transfer devices regularly was implemented in the community. This study contributes to an improved understanding of stored drinking water and risk factors for water contamination in an Arctic context, and adds to limited published literature on water and Inuit health. Ultimately, this study may help to inform communities, public health decision makers, and future research related to water and/or AGI.

Compliance with Ethical Standards

Informed consent: Informed consent was obtained from all respondents, or a proxy respondent for children under 12 years of age.

Conflicts of interest: The authors declare that they have no conflict of interest.

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Tables

Table 1. Variables considered in statistical models as potential risk factors for the outcomes of interest in Rigolet in the June 2014 survey.

<table>
<tr><th>Model One: Total coliforms</th><th>Model Two: AGI</th></tr>
<tr><td>Outcome
Presence of total coliforms in personal stored water containers (dichotomous variable: present/absent)</td><td>Outcome
Self-reported AGI in past 28 days (dichotomous variable: yes/no)</td></tr>
<tr><td>Exposure variables considered
• Age and sex of individual who collected the water
• Water source
• Characteristics of container (e.g. size, material)
• Location of storage container
• Water collection practices
• Water retrieval from container
• Cleaning practices</td><td>Exposure variables considered
• Demographic information (age, sex, household ID)
• Main & secondary sources of drinking water
• Daily volume of water consumption
• Water-handling practices (e.g. water collection, retrieval, in-home treatments)
• Overall ratings of perceived water quality</td></tr>
</table>

Table 2. Demographic information of Rigolet residents: comparison between 2011 Canadian census data and 2014 survey participants.

Variable	Rigolet census (2011) Number (%)	Rigolet survey participants (2014) Number (%)
Population	n = 305 (100)	n = 246 (100)
Sex		
Female	160 (52.5)	121 (49.2)
Male	145 (47.5)	125 (50.8)
Age group (years)*		
0-9	40 (13.1)	41 (16.7)
10-14	15 (4.9)	24 (9.8)**
15-19	15 (4.9)	9 (3.7)
20-24	25 (8.2)	7 (2.8)**
25-64	180 (59.0)	144 (58.5)
65-69	10 (3.3)	10 (4.1)
≥70	20 (6.6)	11 (4.5)

*Globally significant (p=0.028)

**Proportion significantly different from 2011 census (using a two-sample test of proportions)

Table 3. Stored drinking water in Rigolet, 2014. Excludes purchased water.

Water Storage	**n (%)**
Households with stored water	76 (77.6)
Households without stored water	22 (22.4)
Number of container samples taken	104
Water Sources	
PWDU	100 (96.1)
Tap water	2 (1.9)
Brook water	2 (1.9)*
Storage containers	**n (%)**
Material	
Plastic	102 (98.1)
Other	2 (1.9)
Type	
Bucket	13 (12.5)
Clear	48 (46.2)
Opaque	43 (41.3)
Size	
<1 Gallon	24 (23.1)
1-3 Gallons	48 (46.1)
>3 Gallons	32 (30.8)
Location of storage container	
In the refrigerator	44 (42.7)
Outside the refrigerator	59 (52.7)
Stored water contamination	
Presence of total coliforms	26 (25.2)
Presence of E. coli	1 (0.96)
Cleaning practices	**n (%)**
Use of cleaners	
Bleach/chemical cleaners	1 (1.0)
Soap	36 (36.0)
Plain water (hot or cold)	5 (4.8)
PWDU rinsing nozzle	15 (15.0)
Frequency of cleaning	
Never	43 (43.0)
Once per year or less	16 (16.2)
< Once/week	12 (12.1)
≥ Once/ week	28 (28.3)

* Note: In some circumstances, the water that individuals reported drinking as secondary water in the past two weeks (displayed in Fig 3), was no longer (or not) stored in the household at the time of data collection.

Figures

Fig. 1 A map of the four settled Inuit Land Claim Areas in Canada, and the five Inuit communities comprising the Nunatsiavut settled Land Claim Area, as of 2016

Fig. 2 Drinking water sources in Rigolet include tap water (a), store-purchased water (b), local brook water (c), and PWDU water (d). Common types of storage containers include narrow-mouthed 3-gallon jugs (e), plastic buckets with dippers (f & g), and 5-gallon jugs with hand pumps (h)

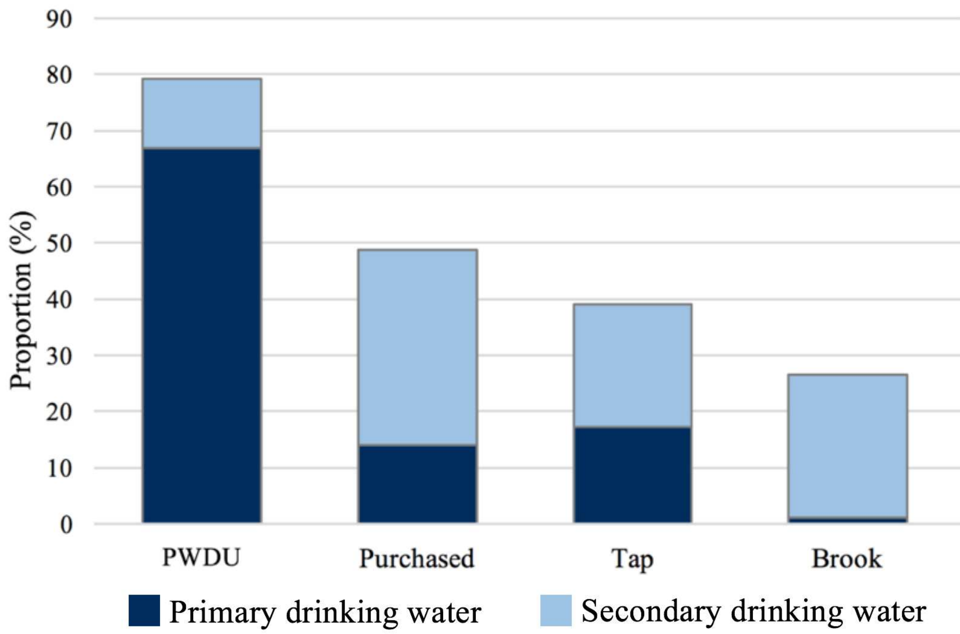

Fig. 3 Use of various water sources as primary and secondary drinking water in Rigolet, Nunatsiavut. Sources available in the community include water from the PWDU, municipally-supplied tap water, store-purchased water, and brook water

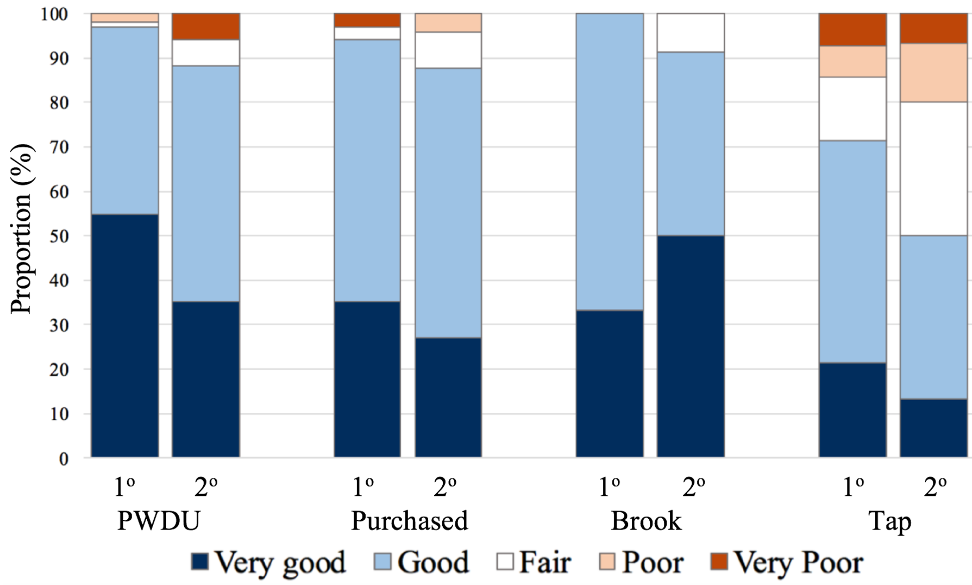

Fig. 4 Ratings of residents' overall perceived quality of their primary (1°) and secondary (2°) drinking water sources in Rigolet, Nunatsiavut

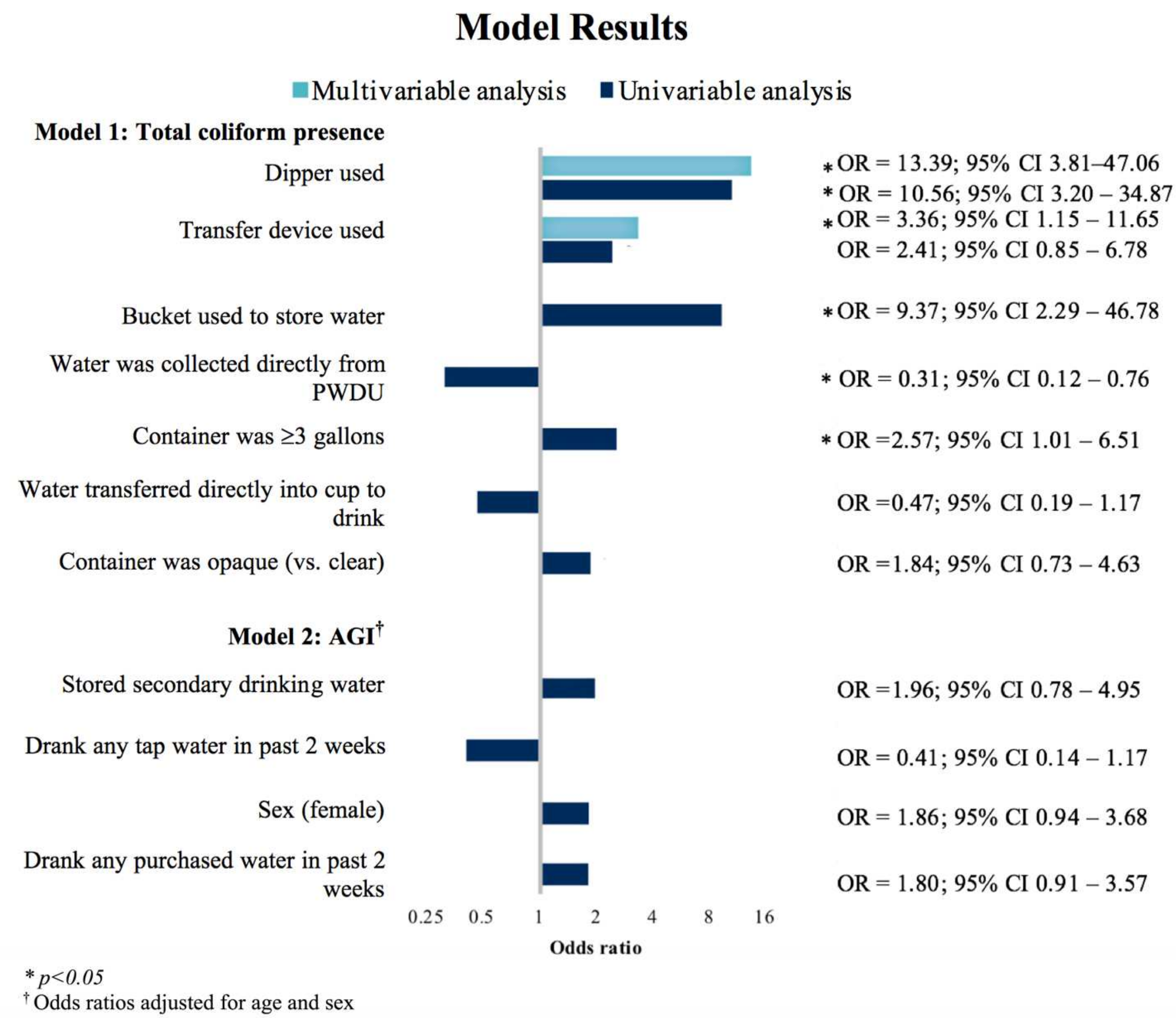

Fig. 5 Results of univariable and multivariable analyses assessing the impact of independent variables on odds of (1) presence of total coliforms in stored water containers, and (2) self-reported AGI. Figure includes odds ratios for liberally significant variables ($p \leq 0.2$). Odds ratios adjusted for age and sex are presented for AGI outcome

Appendix A. Equations

Eq. (A.1) Annual incidence rate

$$\frac{\#\ cases}{\frac{1}{2}[(number\ at\ risk)+(number\ at\ risk-cases)]} \times \frac{365}{28-day\ recall\ period}$$

Eq. (A.2) Standard error (rate)

$$\sqrt{\frac{cases}{person\ years^2}}$$

Eq. (A.3) 95% confidence interval

$p \pm 1.96(SE)$

Eq. (A.4) Annual incidence proportion

$1-(1-X)^{\frac{365}{28}}$, where $X = \frac{\#\ cases}{Number\ at\ risk - \frac{1}{2}withdrawals}$