Assessing Private Well User's Attitudes Towards Chlorination of Drinking Water

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Abstract

Objectives: In Canada, those who rely on private wells are at approximately 5.2 times greater risk of contracting enteric illness due to contaminated drinking water than those who rely on municipal water systems (4). In recent years, some communities have expressed opposition towards chlorination and distrust towards health authorities mandating its use (5,6). Given that chlorination of drinking water is a widely used and highly effective method of limiting waterborne illness, the purpose of this research aims to determine if there is a relationship in the public between perception of the health risk of microbial contamination in drinking water versus attitudes towards chlorination among those utilising non-municipal water systems and private wells in Canada.

Methods: A self-administered survey was distributed through Survey Monkey in order to collect responses from online forum communities throughout Reddit and Facebook. Results from the survey were exported from Survey Monkey and underwent Chi-square statistical analysis using NCSS 12 software.

Results: 97 participants in total responded to the survey, with 74 participants fully completing the survey and providing analysable data. There was found to be a significant association between the perceived level of danger from fecal microbial contamination of well water and acceptance of chlorination in well water systems ($p = 0.0264$). Those who perceived greater danger from fecal contamination were more likely to support chlorination of water used for drinking. There was found to be no significant association between knowledge of the risks and effects of microbial contamination of well water and acceptance of chlorination in well water systems ($p = 0.2246$). Those who had higher knowledge of the risks that contribute to biological contamination, and the health effects, were not more or less likely to support chlorination of personal drinking water.

Conclusion: Based on this study, those who recognize a higher potential for danger from fecal contamination of drinking water are more likely to prefer to chlorinate their water as a result. These results may be used to develop more effective promotional material for rural Canadians on private wells to encourage chlorination as an option where it is necessary.

Key Words: chlorine, chlorination, private wells, knowledge, opinion, drinking water, public health, contamination, fecal

Introduction

Chlorination has been a widely used disinfection method for drinking water for over a century (1). Chlorine may be added as a short-lived but powerful primary disinfectant, and as a secondary residual disinfectant that helps inhibit biofilm formation, while also serving as a potential indicator of microbial growth and breaches within a distribution system (1). A variety of forms of chlorine, including those used for both primary and secondary disinfection may be used in water systems in order to protect users from microbes such as pathogenic bacteria and viruses (3). Pathogens are a particular risk in systems that draw from surface water sources, as these are the more at risk of biological contamination from wildlife and the environment than those drawing from groundwater sources (3). Those on non-chlorinated private wells and private systems are potentially at the highest risk of waterborne illness due to lack of consistent monitoring and governmental oversight (2).

In recent years, some communities have expressed opposition towards chlorination and distrust towards health authorities mandating its use (5,6) The individuals within these communities represent may or may not represent public minority within BC as a whole in terms of their opposition towards drinking water chlorination, but they may provide an insight towards the reasoning behind pushing back against this practice. Knowing the public's perception of the health risks and aesthetic problems associated with consumption of chlorinated water, as well as the public's level of knowledge regarding microbial threats to water may be useful in developing more effective promotional campaigns and communication strategies for health officers in areas where there is opposition to chlorination as a needed health intervention.

The Perceived Health Risks of Chlorine/Chloramines in Drinking Water

The Guidelines for Canadian Drinking Water Quality lists the maximum allowable concentrations (MACs) for various chemical and physical parameters in drinking water based on their short and long-term health effects, as well as their ability to interfere with treatment processes or infrastructure of a water system (7). Chlorine is not listed with an MAC, with the reasoning provided that a guideline value is not necessary at the low concentrations that are found in disinfected drinking water (7). More relevant is the fact that free chlorine forms disinfection by-products (DBPs) upon reaction with organic material, including chlorate, chlorite, N-Nitroso dimethylamine (NDMA), and trichloromethane(chloroform) depending on the type of chlorination used(8). Of these, the most common DBP is trichloromethane. It is listed with an MAC of 0.1 mg/L with Health Canada citing its potential as a carcinogen, particularly for kidney and colorectal cancers(7).

Dissemination of some studies among the public may cause unwarranted worry, irrespective of their validity. Those who have not yet formed an educated opinion on chlorination may decide that the risks posed by these studies will outweigh the benefits that chlorination provides. Various literature has been published on the effects of DBPs on human health(8–10). A study by Chodhury et al. (8) estimated cancer risks throughout Canada from exposure to trichloromethane through ingestion as well as dermal contact and inhalation from showering. The paper cites that the Canadian Cancer Society reported an average of 1660 cases of bladder cancer in Ontario per year. Based on the study's evaluation of cancer risk, Chodhury et al. predicted that 235 cases per year were attributed to possible exposure to

trihalomethanes in drinking water. Research providing data that does not support cancer risk from DBP exposure also exists (7). An earlier study assessing the risk of pancreatic cancer after exposure to DBPs, Do et al. determined that there was no significant association (9). Dermal and inhalation exposure; however, was not included in their analyses. In addition to their potentially carcinogenic properties, DBPs have also been associated with impairing fetal development in pregnant women (8). Säve-Söderbergh et al. conducted a study in Sweden, where the national guideline for trihalomethanes is also 100 ppb(10). The authors found that there was a dose-dependent association of DBP exposure with increased risk of SGA (small for gestational age) among newborns(10). This association; however, only existed with exposure to areas using hypochlorite; in other words, primary disinfection, but not with areas that used solely chloramines in their treatment process. This may be due to the differences in the types and composition of disinfection by-products that form in one type of treatment versus the other.

Regardless of whether there are substantial health risks associated with exposure to DBPs, they are only formed after reaction with organic material (9). A water system's DBP levels can be controlled as long as it is protected from outside contamination and diligently maintained by the operator, though the concerned public may not be aware of this and assume that these chemicals are added directly into their water supply.

Aesthetic Concerns Over Chlorination

Perhaps a more common cause of opposition towards chlorination arises from the perceived aesthetic issues that accompany this type of disinfection method. Flavor and odor of potable water can be affected following chlorine disinfection, although the extent to which it can be perceived can greatly vary between individuals (12-14). As with potential health effects, it is the reaction with organic compounds that is largely responsible for issues. Dichloramine and trichloramine, produced from monochloramine as a residual disinfectant, are often responsible for causing complaints due to taste and odor (9). Smell and taste associated with chlorination are consistently among the top aesthetic complaints mentioned in studies assessing perceived water quality (12–14).

The ability to detect flavor and odor caused by chlorine tends to vary between geographic regions as shown by Piriou et al. (11). It was seen that in general, the higher sensitivity one has to chlorine, the lower the acceptance of chlorine-treated water. Comparisons between individuals from different countries shows that there is variation between acceptance of chlorination based on aesthetics. A complementary study by Doria et al. (14)adds to these results, mentioning that perception of risk associated with drinking water could be related to the social context of where one lives. For example, those in the UK were more concerned with exposure to chemicals in drinking water and addition of anthropogenic chemicals than those living in Portugal. In BC, there may also be a discrepancy in the perception of risk and the ability to detect flavor and odor differences in chlorinated water between rural and urban populations.

In Newfoundland, it has been found that there is a tendency for older, higher educated, and high-income users to have a high level of satisfaction with their water quality as compared to younger, less educated, and low-income users (12). This is regardless of the actual aesthetic quality of the water, as measured by levels of colour, manganese, total dissolved solids, iron, and trihalomethanes. Individuals commonly complained of aesthetic issues, even when there were no parameters that exceeded

aesthetic objectives (12). Conversely, many individuals were satisfied with their water even when some parameters exceeded aesthetic parameter guidelines. These discrepancies seem to indicate that actual water quality often does not inform people's perceptions of water quality. It seems that beyond how sensitive an individual may be to certain tastes and smells, sociodemographic factors can also have a significant impact on perception of water quality. The separation between perceived and actual water quality among the public may be due to a lack of resources in obtaining information on water test results, and a lack of communication with regional authorities.

Public Awareness of the Risks of Biological Contamination of Wells

In Canada, those who rely on private wells are at approximately 5.2 times greater risk of contracting enteric illness due to water consumption than those who rely on municipal water systems (4). Because of a lack of knowledge as compared to a qualified operator, many of these individuals never become aware of risks to their water supply until they have become sick, or perhaps even long after the fact. Therefore, increasing public awareness of the biological risks that may be involved in not chlorinating well water could increase the frequency of testing for bacteria among private well users. It is recommended that private well users test their water at least once a year. Using surveys and Public Health Ontario Laboratories well water testing data, Ugas et al. (4) found that for owners of private wells, having previous positive results for bacteria was the most significant reason for being a frequent tester. Another study examining the perceptions of residents who use private systems analyzed opinions of water safety, sensory quality of water, and in-home treatment devices for water with regard to the level of water testing they performed (15). The study showed that despite common concerns over bacterial and chemical contamination from nearby agriculture, testing overall was done less frequently than recommended by the province and participants were largely confident in the safety of their water. Lack of knowledge was presented as one of the factors as to why there was a lack of urgency in testing, as residents did not have a clear idea of the risk that water contamination from agricultural activities could pose to their health. In fact, participants expressed need for information on water testing and water supplies. As seen before, older participants had higher more positive perception of their water quality than younger participants. Incidentally, some of the reasoning that participants described having "excellent" water quality involved mention of "no chlorine", "no smell", and "great tasting (15)."

More recent research has been conducted in BC in order to gauge the level of awareness among the public regarding the health impacts of microbial contamination of drinking water (16,17). Henrich et al. found that in BC there is a lack of recognition of the health implications behind biological contamination of drinking water and that there was generally a low concern about fecal contamination affecting source water quality compared to chemical contaminants. Comparing opinions of surveyed drinking water experts with general public residents, residents did not see microbial hazards as a large threat to drinking water, while experts rated them among the highest concerns. This lack of concern in residents of contamination of water systems by pathogens may result in apathy towards chlorination among the larger public when it should be among the highest concerns for water safety, in agreement with expert opinion. These studies explicitly indicated the public's desire for more easily accessible information regarding water quality through focus group interviews. As

Henrich et al explain, “In all four groups participants thought the best way to facilitate behaviour change is through education and improving awareness. They explained that people would be less likely to engage in activities that negatively impact water quality if they knew which activities did so… In two focus groups, participants felt that there is currently not enough information provided when contamination events occur and that they would like to have an improved alert system to notify the public of these events (17).”

More effective avenues of communication between health authorities and the public regarding the most prevalent safety risks in drinking water are common themes in most of the literature previously discussed.

Research Objective

Given that rural individuals who rely on surface water are at the greatest risk of waterborne illness, the purpose of this research aims to determine if there is a significant relationship between perception of the risk of microbial contamination in drinking water versus attitudes towards chlorination among those utilising non-municipal water systems and private wells in Canada. Results of this study may be useful in developing more useful communication strategies with the public regarding this issue.

Methods and Materials

Description of Materials

A self-administered survey was distributed through Survey Monkey (18), which required use of an internet-accessible computer as well as a Survey Monkey license provided by BCIT. A financial incentive in the form of a $100 Visa gift card was randomly awarded to one participant upon completion of the study through contact via mail. The results from the survey were exported from Survey Monkey and collected onto a spreadsheet using Microsoft Excel software which was then statistically analysed using NCSS 12 (19).

Description of Methods

The online survey platform Survey Monkey was used to generate the self-administered questionnaire for this study. This method of delivery was chosen due to the time and cost efficiency provided by online distribution of surveys (20), as well its the potential to reach a broad population within Canada which was important for this study. The survey was distributed via email and social media websites including Facebook and Reddit. The reddit forums that the survey was posted in included r/Langley, r/MapleRidge, r/Abbotsford, r/Cowichan, r/Squamish, r/northernontario, r/SampleSize, and r/takemysurvey. The survey was also posted in public survey promotion facebook groups.

In addition to descriptive data including age, gender, and educational status, three broad categories of questions were asked in the survey. These three categories were: perceived level of danger from fecal microbial contamination of private well water, level of knowledge of the risks and effects of fecal microbial contamination of private well water, and level of acceptance of chlorination in private well systems. Knowledge was assessed based on a knowledge test and participants were each given a score of 0 to 8 based on the correct amount of answers given out of 8 questions and were categorized into 3 groups based on their score (very knowledgeable, some knowledge, and little or no knowledge). A score of 0% to 33% equated to having little or no knowledge, 33% to 66% indicated some knowledge, and over 66% indicated very knowledgeable. The only inclusion criteria for participation in the study was that the participant must have either lived in a residence in Canada that made use of a private well or have been employed at a workplace that made use of a private well in

Canada. No participants were excluded based on age, gender, or educational status.

Statistical Methods

Description of data

The data collected was nominal, except for the ages of the participants. A combination of multichotomous nominal, multichotomous ordinal, and dichotomous questioning (21) was used throughout the survey. Knowledge level of participants was separated into three categories: very knowledgeable, some knowledge, and little or no knowledge based on their total score.

Descriptive statistics

Descriptive information collected included age, gender, educational status, and presence of an on-site sewage system at either the residence or workplace of the participants. 97 participants in total responded to the survey, with 74 participants fully completing the survey and providing analysable data. Figures 1 through 3 describe the age distribution of survey participants, gender distribution, and level of education of survey participants. Figure 4 shows the proportion of participants who had an on-site sewage disposal system.

Figure 1. Age Distribution of Survey Participants

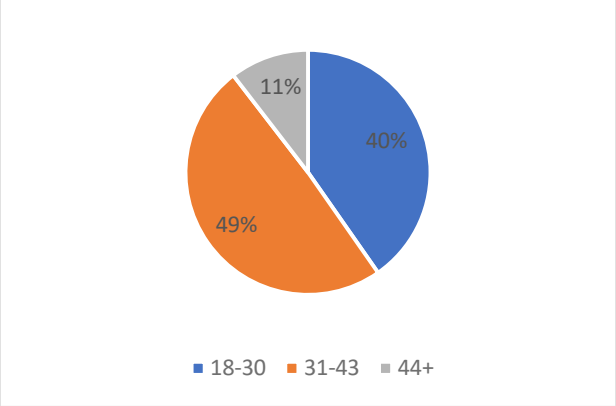


Figure 2. Gender Distribution of Survey Participants

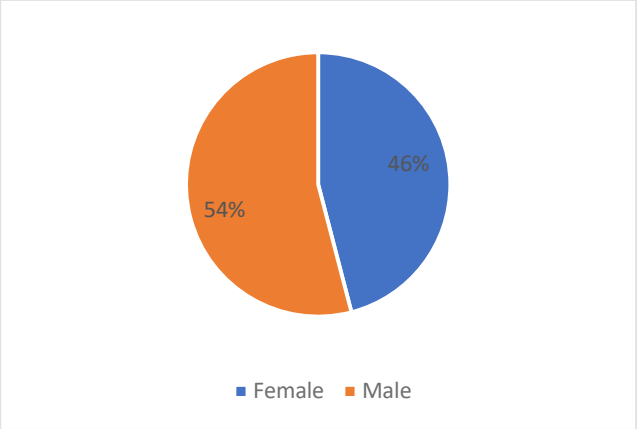


Figure 3. Level of Education of Survey Participants

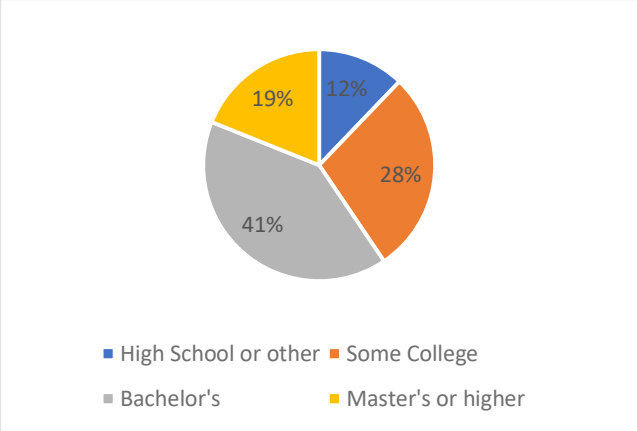
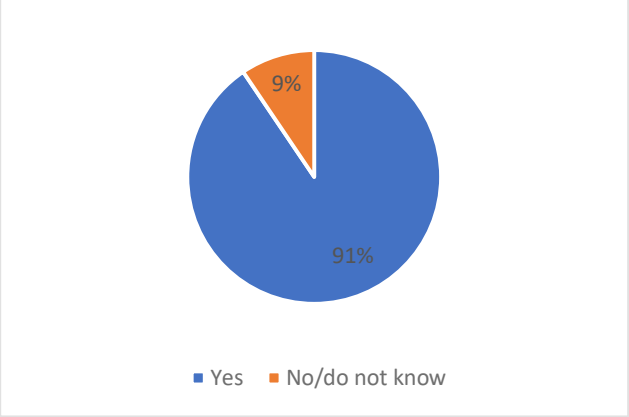


Figure 4. Proportion of Participants with an On-Site Sewage System



Inferential Statistics

Data was analysed via chi-square tests using NCSS 12 software, as this study compared proportions between three nominal data sets (knowledge level, perceived contamination danger, acceptance of chlorination). Two sets of hypotheses were tested for the purposes of this study:

Ho_1:	There is no statistically significant association between the perceived level of danger from fecal microbial contamination of well water and acceptance of chlorination in well water systems.
Ha_1:	There is a statistically significant association between the perceived level of danger from fecal microbial contamination of well water and acceptance of chlorination in well water systems.
Ho_2:	There is no statistically significant association between knowledge of the effects of microbial contamination of well water and acceptance of chlorination in well water systems.
Ha_2	There is a statistically significant association between knowledge of the effects of microbial contamination of well water and acceptance of chlorination in well water systems.

Table 1: Study Hypotheses

The Pearson's Chi-Square test results were read to determine if there were statistically significant associations in the hypotheses. For hypothesis 1, $p = 0.0264$, therefore Ho_1 was rejected and there was a significant association between the perceived level of danger from fecal microbial contamination of well water and acceptance of chlorination in well water systems. Those who perceived greater danger from fecal contamination were more likely to support chlorination of water used for drinking. There is a notable potential for alpha error with this result (22), as a lower p-value cutoff of 0.01 would have resulted in acceptance of Ha_1. For hypothesis 2, $p = 0.2246$, therefore Ho_2 was not rejected and there was found to be no significant association between knowledge of the risks and effects of microbial contamination of well water and acceptance of chlorination in well water systems. Based on this result, those who had higher knowledge of the risks that contribute to biological contamination, and the health effects, were not more or less likely to support chlorination of personal drinking water. Given that the final sample size was small at 74 participants, the power for this study is relatively low, and therefore contributed to the possibility of a type II error for the acceptance of Ho_2

Discussion

The results showed an association between perceived danger from fecal contamination of drinking water and acceptance of chlorination (Table 1). Those who perceived a higher danger to health from drinking water contaminated with fecal matter were more likely to favor chlorinating their drinking water. As at least 91 % of participants also had an on-site sewage system on the same property as their wells, the opportunity for contamination of drinking water with fecal pathogens such as *E. coli* O157:H7 represents a potential risk for most individuals utilizing a private well. While shallow wells are under greater risk, deep wells are also vulnerable to contamination from sewage outbreak events or waste from agriculture (23), meaning all private well owners should be aware of the precautions to take during a contamination event. The studies performed by Henrich et al. indicated that the public is generally more concerned with regard to chemical contaminants in drinking water rather than

biological contaminants (16,17). Although this study does not directly compare participants' relative sense of danger from chemical contaminants (e.g. arsenic or toluene) to fecal contamination such as in the studies performed by Henrich et al. , concern over fecal contamination may be a driver for adopting safer drinking water practices, which may include installation and maintenance of a chlorination disinfection system. Well owners should regardless be educated on the fact that chlorination is not a foolproof method of protecting the biological safety of their drinking water supply, as there are fecally-transmitted pathogens that are highly- resistant to chlorine disinfection, such as *Cryptosporidium* spp. and *Giardia* spp. (24). This is seen in the knowledge assessment portion of the survey, as 69% of participants in the study either responded that chlorination is effective at eliminating all microbes in drinking water or did not know if it is effective at eliminating all microbes.

The association between drinking water safety knowledge and acceptance of chlorination

The results did not show a significant association between the level of drinking water safety knowledge and acceptance of chlorination (Table 1). Despite evidence suggesting that a higher level of knowledge and awareness regarding drinking water may influence behavioral change (15,16,17), there is no evidence within this study to suggest that this applies to chlorination of drinking water. The results of the survey did, however, show that there may be common gaps in knowledge among private well users regarding both the effectiveness of chlorination and the ability to interpret bacteriological test results for drinking water (Appendix C). Though this study suggests that education-focused approaches may not be effective in changing attitudes toward chlorination, these areas may still be investigated in future studies as areas to potentially focus on for promotion of drinking water safety in general.

In addition, there was not found to be a significant association between overall level of education and acceptance of chlorination (Appendix A). This is inconsistent with the study performed by Ochoo, Valkour, and Sarkar regarding aesthetic concerns due to chlorine by-products (12); however, this current study has lower power due to its relatively small sample size.

Knowledge Translation

Results of this study can be considered when developing drinking water safety awareness material for the public within rural areas. As perceived danger from fecal contamination is associated with higher acceptance of chlorination, incorporating historical examples of drinking water outbreaks and the consequences of inadequate disinfection in promotional campaigns may be effective in changing behavior toward chlorination. The Walkerton *E.coli* outbreak that occurred in Ontario in 2000 (26) is one such event that has influenced legislation throughout Canada by highlighting the need for adequate disinfection practices and due diligence in maintaining drinking water quality, and is an example that can be reiterated on for health promotion. This could be especially beneficial for those living on farmlands who have their drinking water at risk of contamination from agricultural activity.

Limitations

Given that the respondent sample size was relatively small (n=74), the study has low power and may not be representative of rural Canadian's overall opinions regarding chlorination and drinking water safety knowledge. BC and Ontario populations were the only two provinces surveyed due to restrictions related to less online subreddit presence from other provinces and difficulty

obtaining permission to post the survey on certain subreddits and other forums.

The survey formatting was easily analysable but led to a limited type of questioning as open-ended opinions regarding chlorination and potential reasons for disapproval were not collected. Additionally, the ability for participants to guess correct knowledge answers was possible due to the closed-ended questioning method that the survey utilized.

The method of survey distribution was biased toward younger individuals, some of whom may not be the principal owners of private wells and therefore are not directly responsible or involved in supervising the safety of their drinking water. Since seniors aged 65 and over represent a larger proportion of rural populations than urban populations (29), an in-person physical survey handed out at locations within rural areas would have been more effective to reach this target population. This was not carried out due to time limitations, and therefore the external validity of this study was reduced.

Future Research

This study did not further elaborate on the root causes for disapproval of chlorination such as various aesthetic or health concerns that survey participants may have had with regard to drinking water. There may be an association between water safety knowledge and disapproval of chlorine due to potential health concerns, but this was not assessed in the current study due to time and survey limitations.

-Future studies examining attitudes towards chlorination or drinking water safety knowledge specifically among Indigenous communities may be beneficial as these are among the most neglected groups in terms of access to funding for adequate water treatment and training for water system operators. It has been reported to be relatively common among Indigenous community members to express distrust with regard to drinking water treatment processes (25).

Conclusions

Chlorination is the most commonly used method of disinfection that can protect users from many waterborne illnesses. Based on this study, those who recognize a higher potential for danger from fecal contamination of drinking water are more likely to prefer to chlorinate their water as a result. Second, a higher level of knowledge regarding drinking water safety does not have an effect on whether an individual prefers to chlorinate their drinking water. These results may be used to develop more effective promotional material for rural Canadians on private wells to encourage chlorination as an option where it is necessary.

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Competing Interest

The authors declare that they have no competing interests for this study.

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