Arsenic consumption and health risk perceptions in a rural western U.S. area

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Abstract

Churchill County, Nevada had approximately 23,000 residents, with an estimated 13,500 who relied on private wells for water supply in 2002. This study examined exposure to arsenic in water supplies among residents with private domestic wells and factors related to householder choice to consume tap water. It compared opinions and concerns about water quality with consumption habits and observed concentrations from tap water samples. The results from 351 households indicated that a majority (75%) of respondents consumed tap water and that a minority (38%) applied treatment. Approximately 66% of those who consumed tap water were exposed to concentrations of arsenic that exceeded 10 ppb. Water consumption was related to application of treatment. Among 98 respondents who were not at all concerned about the health effects of aqueous arsenic, 59 (60%) reported consuming tap water with concentrations of arsenic exceeding 10 ppb. Conversely, among 86 respondents who were highly concerned about arsenic, 33 (37%) consumed tap water with concentrations of arsenic exceeding 10 ppb. Results from a national sampling effort showed that 620/5304 (11.7%) of private wells sampled had arsenic concentrations above 10 ppb. The paradox of awareness of arsenic in water supplies coupled with consumption of aqueous arsenic in concentrations of >10 ppb may be common in other parts of the nation. Enhanced educational efforts, especially related to tap water sampling and explanations of efficacy of available treatment, may be a useful means of reducing exposure through private water supplies.

Key terms: <u>public health</u>, water quality, drinking water, arsenic, metals

Introduction

In the United States, the Safe Drinking Water Act and amendments apply to public water supply systems. The standard for arsenic in drinking water recently was revised from 50 to 10 ppb, effective 2006 ((40 CFR 141.62(b)(16)). The World Health Organization has maintained a guideline of 10 ppb since 1993 (WHO 2004). Private water supply systems, such as domestic wells that serve single residences, are not subject to any aspect of regulation associated with the Safe Drinking Water Act, including standards for operation, testing and conformance with the maximum contaminant levels set for public health protection. Use of such wells is common in rural areas throughout the United States.

Approximately 23,000 people reside in Churchill County, Nevada. Of these, an estimated 5500 households with 13,500 residents relied on private domestic water supplies in 2002 (personal comm. Churchill County Planning Department, 2002). Churchill County recently attracted national attention because of concern related to an abnormally large number of children diagnosed with acute lymphocytic leukemia in the summer of 2000 (Steinmaus, Lu et al. 2004). Although unrelated to arsenic in groundwater, investigations of the cluster led to recommendations by an expert panel convened by the U.S. Centers for Disease Control and Prevention that county residents consider the quality of personal supplies, with special attention to arsenic (Robison, Sinks et al. 2001).

In Churchill County arsenic in groundwater is released from eroded volcanic rock and geothermal sources. Studies of water quality have reported that arsenic concentrations are commonly high and likely to vary significantly throughout the county, which is partly related to the source of water (Lico and Seiler 1994).

Concentrations have been reported to vary over several orders of magnitude, from <1 ppb to more than 1000 ppb (Lico and Seiler 1994). Variation is due to heterogeneous subsurface lithology, minerology and geothermal influences (Lico and Seiler 1994; Fitzgerald 2004; Seiler 2004). Private wells pump from two alluvial aquifer systems, which are recharged by applied irrigation water (Seiler and Allander 1993).

This study examined exposure to arsenic in water supplies among residents with private domestic wells and factors related to householder choice to consume tap water. It compared opinions and concerns about water quality with consumption habits and observed concentrations from tap water samples.

Methods

Recruitment and data collection and water sample analysis: Participants were recruited by direct solicitation from a research team and by flyers distributed to homes and businesses in Churchill County. The recruitment strategy was designed to reach a cross-section of the population, with respect to spatial distribution and socio-economic characteristics. As an incentive, participants were provided with a water sample analysis (value of $100, provided by the Nevada State Health Laboratory (a certified public drinking water analysis facility)). The analysis reported concentrations of major anions and cations, some metals (including arsenic) and several aesthetic qualities.

Participants were asked questions about household characteristics and opinions (including consumption of home water supplies, use of treatment devices, level of concern about drinking water quality in general and arsenic in water supplies, and opinion of health risks associated with drinking water supplies (Benson 2003)). Questions about water consumption habits asked respondents about types of use (ranging from direct consumption from the tap and in mixed beverages to minor uses such as making ice). Respondents were considered to consume tap water if they indicated that they drank or made beverages with tap water.

The questionnaire also requested information about water treatment choices. At the time of the survey (2002) the National Sanitation Foundation (www.nsf.com) recognized only reverse osmosis and distillation as being effective treatments to remove arsenic. Respondents were asked whether they treated home supplies and were asked to select the type of treatment applied from a list that included reverse osmosis, distillation, several types of carbon-based filtration systems, simple filtration systems, softeners, pH neutralizers and several types of disinfection systems (Benson 2003). For preliminary data analysis (see Figure 1), application of treatment was considered as a simple binary classification variable, with respondents either treating water by any of the means noted above, or not treating water. For purposes of data analysis related to health risk perception (see Table 3 and statistical analyses in the "Results" section) answers from respondents about treatment were coded in one of three categories: (a) treatment applied was considered to be effective in removing arsenic, (b) no treatment was applied, or (c) the treatment applied was not considered to be effective in removing arsenic.

The study area, within the Churchill County boundary, was approximately 225 square miles and excluded the service districts of public water supplies, the largest of which served the city of Fallon (the county seat (**Figure 1**.)). Approximately 10,750 people lived in the study area (U.S. Census 2000, available at www.census.gov).

Sampling and analytic protocols: Tap water samples were collected from the point of most frequent water use in the home identified by the respondent, which was usually a kitchen faucet. Collection involved minimal purging to simulate home use habits (approximately five seconds of flow prior to collection). Arsenic concentrations were determined by the Nevada State Health Laboratory (a certified drinking water analysis facility) using EPA method 200.8 (ICP-MS) for samples with turbidity less than 1 NTU and ASTM method D2972-93B (Hydride generation AA) for samples with turbidity greater than or equal to 1 NTU.

Results

Sampled and general population characteristics: The sample consisted of 351 respondents, from households dispersed throughout the county (**Figure 1**). Comparison with results of the 2000 U.S. Census (www.census.gov) indicated slight discrepancies between the sample and population proportions of homeowners and renters, proportions of 18-30 year old respondents, proportions of those with less than a high school education, proportions of those with income exceeding $75,000 per year and proportions of males versus females (Benson 2003). **Table 1** compares sampled with population demographic characteristics.

Tap Water Sample Results: Arsenic concentrations in tap water samples were highly varied (ranging from < 3 ppb (analytical detection limit) to 2100 ppb (**Table 2**), as would be expected given the heterogeneous nature of the aquifers used for private domestic supplies (Glancy 1986; Lico, Welch et al. 1986; Maurer, Johnson et al. 1994; Seiler 2004). The distribution of sample concentrations (**Figure 2**) indicates that the majority of tap water from domestic wells in Churchill County had concentrations of arsenic that exceeded 10 ppb. The minima, medians and maxima for each group depicted in reported in **Table 2**.

Consumption, Treatment and Exposure to Aqueous Arsenic: A majority of respondents (262/351, 75%) reported that they consumed tap water. A minority (134/351, 38%) reported treating tap water. Of those that applied any type of treatment, a majority (116/134, 86%) consumed tap water. Of those who applied treatment, 63/134 (47%) applied reverse osmosis (62 respondents) or distillation (1 respondent). Of those that did not apply treatment, a majority (146/217, 68%) consumed tap water. **Table 2** reports the minimum, median and maximum concentrations for those who reported consuming tap water, categorized according to presence of treatment. The distribution of concentrations in tap water consumed by respondents is presented in **Figure 2**.

Concern about water quality and influence on choice to consume tap water: The questionnaire administered to survey participants requested information about application of treatment and treatment type, levels of concern about water quality in general and arsenic in water specifically, perceptions of health risks associated with drinking water and whether or not respondents consumed tap water **(Table 3)**. We sought relationships between responses to these questions using correspondence analysis based on the χ^2 distribution with cross-tabulated results. **Table 3** contains summary information received from respondents about each of these topics. Null hypotheses tested focussed on statistical independence between the following factors:

- levels of concern about water quality in general and concern specifically about arsenic in water supplies;
- application and type of treatment applied and whether respondents consumed tap water;
- perception of health risks posed by drinking water supplies and whether respondents consumed tap water; and

- perception of health risks posed by drinking water supplies and concern about arsenic in water supplies.

Results of Analysis of Cross-tabulated Data

Levels of concern about water quality in general and concern specifically about arsenic in water supplies: The relationship between concern about water quality in general and concern specifically about arsenic in water favored rejection of the null hypothesis that these concerns are independent (p=0.000+). Although there are many types of concerns related to quality of water from private wells in Churchill County, arsenic is a predominant issue. In fact, records kept of inquiries about water quality by a water supply specialist working for University of Nevada Cooperative Extension indicate that the vast majority of questions and concerns between March 2003 and February 2005 were related to arsenic in water (A. Fisher, University of College of Agriculture, Biotechnology and Natural Resources, Cooperative Extension, Fallon, Nevada, personal communication, 7/2005). The questions and concerns may be prompted by ongoing news coverage of arsenic in public and private water supplies. In fact, 113 news stories from March 2003 – July 2005 focussed on or mentioned arsenic in groundwater (A. Fisher, ibid.).

Application and type of treatment applied and whether respondents consumed tap water: The correspondence between treatment of water and consumption is especially strong. The null hypothesis of independence of these factors was rejected in favor of the alternative (the factors are not independent) at p=0.000+. Odds ratios (with 95% confidence intervals) of consumption given any treatment, correct treatment and other treatment indicated that respondents were 2.88 (95% confidence interval: 1.64–5.07) times more likely to consume tap water if any treatment were in place, 4.52 (1.86–10.99) times more likely to consume if treatment recognized as being effective for removing arsenic were in place and 2.12 (1.10–4.13) times more likely to consume if treatment not recognized as being effective for removing arsenic were in place. This suggests that householders who invested in treatment systems, especially those considered to be effective for removing arsenic, were more likely to consume tap water than those who did not apply treatment.

Perception of health risks posed by drinking water supplies and whether respondents consumed tap water: The relationship between perception of health risks posed by drinking water supplies and whether respondents consumed tap water was not independent (p=0.000+). In fact, respondents were 5.28 (2.42−11.48) times less likely to consume tap water if they held the opinion that there were health risks associated with their drinking water, compared with those who felt there were not health risks or didn't know whether there were health risks.

Perception of health risks posed by drinking water supplies and concern about arsenic in water supplies: The null hypothesis of independence was rejected at a high level of significance (p=0.000+), suggesting that these are related. A respondent was approximately 0.32 (0.10–0.99) times as likely to be unconcerned or not know about health risks associated with drinking water if the same respondent was very concerned about arsenic in drinking water. This suggests that respondents recognized that arsenic in water supplies could be a health threat, which corresponded with the results from the first hypothesis tested above.

Discussion

Among these respondents, levels of concern about both arsenic and water quality in general were correlated, suggesting that a respondent's level of concern about water quality mirrored the level of concern about arsenic. Awareness of arsenic as a potential contaminant in local groundwater may have been related to the amount of information available through television, radio and especially locally distributed newspapers. However, the levels of concern about water quality and arsenic in water were not uniformly high. In fact, the majority of responses to the question of level of concern about arsenic in drinking water (**Table 3**) was distributed at the extremes, with approximately 28% of respondents being not-at-all concerned and 25% being highly concerned. Levels of concern about water quality in general and arsenic were correlated through a distribution that had clusters of respondents at the extremes, with no significant trends.

In spite of a fairly constant flow of public information about the occurrence of arsenic in groundwater, approximately 28% of respondents (98) were not concerned at all about arsenic in water. Among this group of 98, 59/98 (60%) reporting consuming tap water that testing showed had concentrations of arsenic greater than 10 ppb. Conversely, among those who reported being highly concerned about arsenic in water (86 respondents), 33/86 (37%) respondents reported consuming tap water, with concentrations of arsenic that testing showed contained > 10 ppb. This suggested that concern led to reduced likelihood of consumption, though a significant proportion of those who were highly concerned consumed tap water that exceeded the standard for arsenic.

Among those who indicated a high level of concern about arsenic in water there was a significant gap in understanding about water quality. In spite of having high levels of concern, respondents exposed themselves to arsenic through consumption at home. This paradox indicates a lack of understanding about the true concentration of arsenic in home drinking water supplies among this subset of the respondents, which is further reflected in responses to a question asked about the standard for arsenic. Respondents were asked to identify the concentration and units of the standard. Although there appears to be a general awareness of arsenic as a contaminant in drinking water supplies, respondents were unclear about the numerical value of concentration and units (**Figure 3**). In fact, 77.5% (272/351) did not cite either the correct units or numerical value; a minority of respondents 12.0% (42/351) was able to correctly identify both. This suggests that respondents based their decision to consume on incomplete information about the actual concentrations of arsenic in water and the significance of concentrations.

Although treatment of any kind led to decreased overall concentrations in tap water (**Figure 2**) respondents who used appropriate types of treatment (reverse osmosis or distillation) were exposed to concentrations of arsenic that exceeded the standard. Among those who applied reverse osmosis or distillation and consumed tap water (63), 34/63 (54%) were exposed to concentrations >10 ppb. Among those who applied reverse osmosis or distillation that testing showed contained more than 10 ppb, 30/63 (48%) felt that their water did not contain concentrations of arsenic that exceeded 10 ppb. This suggests that the investment in treatment led to a false sense of security about home water supplies.

Although reverse osmosis is recognized as an effective means of reducing concentrations of arsenic in water, it may not be effective in producing water that meets the 10 ppb standard if groundwater concentrations are very high. This has been demonstrated in other sampling surveys conducted in the county (such as http://nevada.usgs.gov/fallon/FallonFeb03.ppt -- see slide 4 comparing arsenic in influent groundwater with reverse osmosis treated water concentrations). As an example, if starting concentrations of arsenic are > 1000 ppb, reverse osmosis units operating at peak efficiency (≥ 99% reduction in concentrations of arsenic in influent groundwater) may not reduce concentrations to less than the 10 ppb maximum contaminant level.

Although focussed on a small rural area in the western United States, the apparent paradox of concern about arsenic and consumption of tap water with concentrations that exceed the national standard for arsenic in public water supplies may have important implications for other areas. Private wells associated with residences serve a minority of the U.S. population, especially in rural areas. Of 5304 private, domestic wells sampled in the U.S. as part of the National Water Quality Assessment program from 1973 – 2001 across the United States (including Hawaii, Puerto Rico and Alaska) arsenic concentrations in 620 equalled or exceeded 10 ppb (USGS 2001). This proportion is not representative of all private wells in the United States, but it indicates that private wells in other areas of the country also produce water that is contaminated with arsenic.

Although Churchill County represents an extreme, in terms of concentrations of arsenic that occur in groundwater, publicity about arsenic and exposure through private water supplies, it suggests that, even in the presence of well-publicized concerns about the potential health effects associated with groundwater consumption, private well owners may be unaware of the significance of standards that apply to public water supplies and the potential health effects of contaminants in their drinking water. It is also possible that homeowners have a false sense of security related to application of treatment that may not remove contaminants that cannot be readily sensed by taste or odor. This suggests that educational efforts are needed to help those who rely on private water supplies understand treatment techniques, including expectations for contaminant removal. It also suggests that those who rely on private wells should be encouraged to test water delivered to commonly used taps in the home to evaluate the quality of water that is actually consumed.

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Figure 1: State of Nevada, with study area and sampled points (inset)

Figure 2: Distributions of concentrations of arsenic in all tap water samples, treated and untreated tap water samples and samples from tap water consumed by respondents from treated and untreated sources. Non-detections are shown at half the laboratory detection limit (1.5 of 3 ppb). **Table 1** includes minimum, medium and maximum values for each group.

Figure 3: Respondents were asked to identify the pending maximum contaminant level for arsenic in public water supplies. A minority (11.7%) was able to identify both units and concentration correctly, while the remainder could identify units or concentration or neither.

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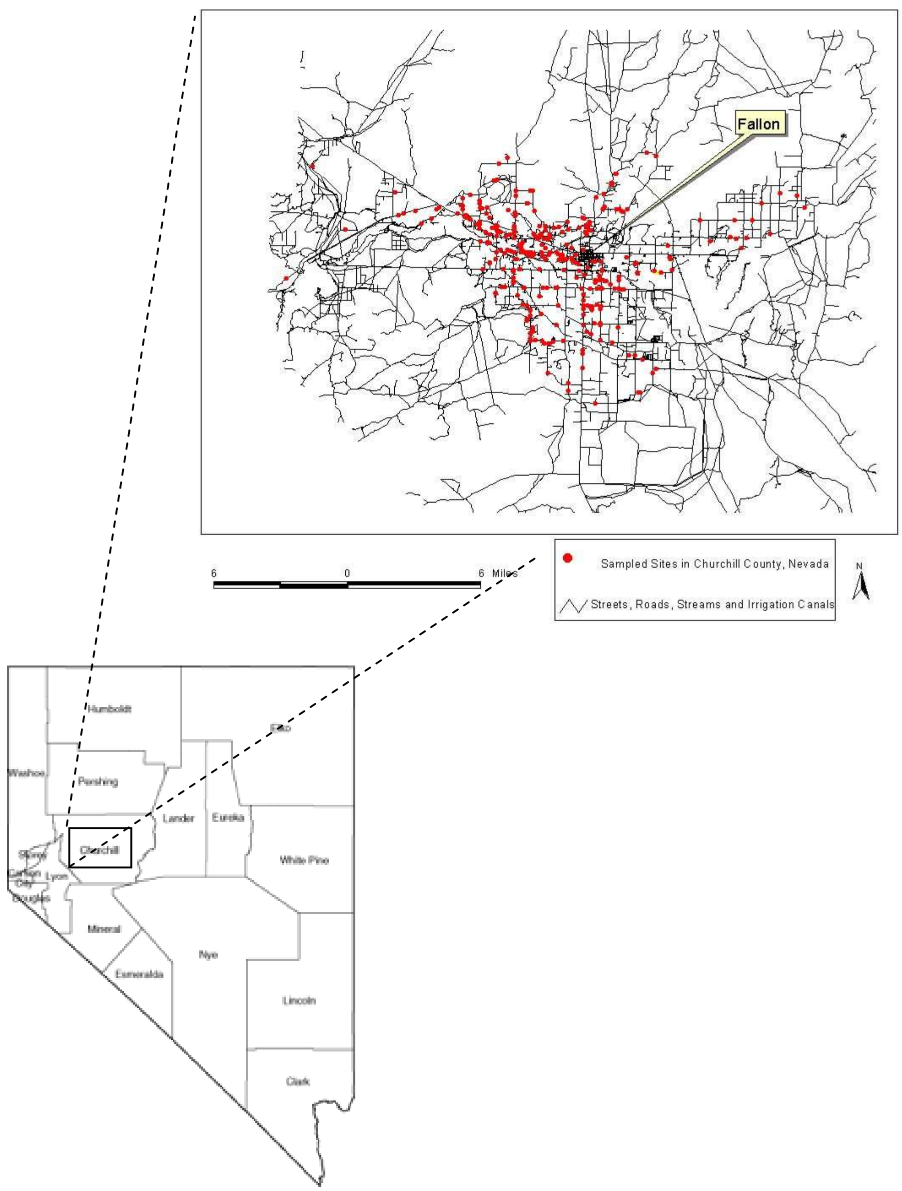

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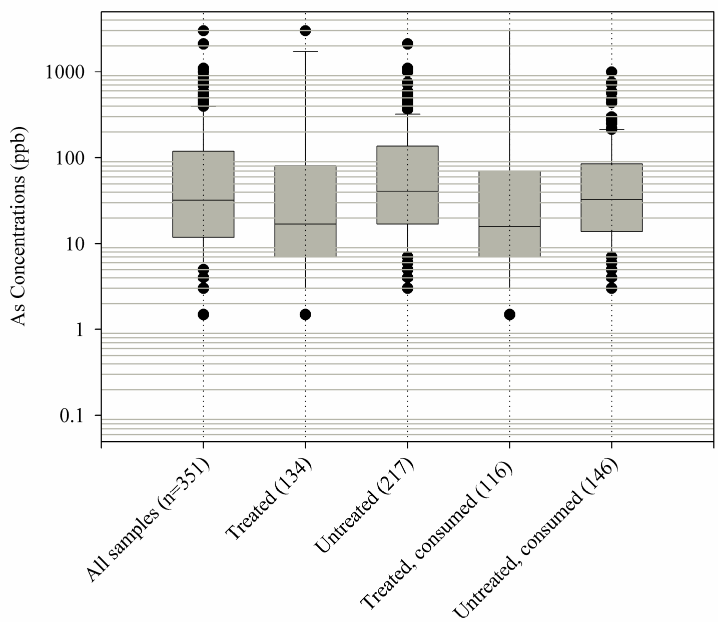

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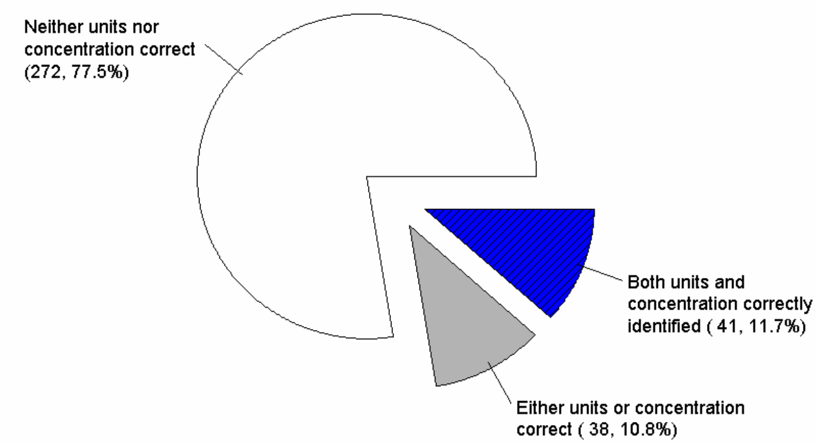

Table 1: Demographic characteristics of sample and population and Churchill County, Nevada in 2002 and 2000, respectively.

Demographic Characteristic	Sample[1]	Population[2]
Median Age (years)	58[3]	34.7
Sex ratio (M/F)	41.0%/59%	50.2%/49.8%
Homeownership (%owners/%renters)	91.2%/8.8%[4]	65.8%/34.2%
Median education	Bachelor's degree	Between "completed high school degree" and "some college"
Median income	$50,000[5]	$40,808
Households with children <18 years old	37.6%	38.9%

[1] Benson, M. 2003. Arsenic in Churchill County, Nevada: Risk Factors Associated with Consumption of Tap Water. M.S. Thesis, University of Nevada, Reno, NV.
[2] US Bureau of Census, 2005. Profile of Selected Characteristics -- Churchill County. http://quickfacts.census.gov/qfd/states/32/32001lk.html
[3] No respondents younger than 18 years old were included in the sample; the US Bureau of Census (see footnote 1) reports that this fraction comprises ca. 30% of the county population.
[4] Rental units are most prevalent within the bounds of public water supply systems (primarily the city of Fallon, NV), which was excluded from the study.
[5] Median is drawn from classes of income reported by 293/351 respondents. The remainder chose not to report income.

Table 2: Minimum, median and maximum concentrations of arsenic (ppb) in tap water samples obtained from Churchill County, Nevada.

	All Samples	Treated	Untreated	Treated and Consumed	Untreated and Consumed
Minimum	< 3	< 3	3	< 3	3
Median	26	13	41	12	33
Maximum	2100	870	2100	870	750
n	351	134	217	116	146

Table 3: Summary of responses related to hypotheses tested

Application of Treatment, and Treatment Type

Treatment applied and considered effective in removing arsenic (National Sanitation Foundation 2002 (www.nsf.com))	63 (25.0%)
Treatment applied, not considered to be effective for removing arsenic	71 (20.2%)
No treatment applied	217 (61.8%)

Level of concern about water quality

Q: "How concerned are you about your water quality?" (1 – 5 = very concerned)

1	2	3	4	5
63 (17.9%)	42 (11.9%)	100 (28.5%)	41 (11.7%)	105 (29.9%)

Level of concern about arsenic in water

Q: "On a scale of 1 to 5, how concerned about you about the level of arsenic in your water?" (1 – 5 = high)

1	2	3	4	5
98 (27.9%)	43 (12.2%)	91 (25.9%)	33 (9.4%)	86 (24.5%)

Perception of heath risks associated with drinking water

Q: "Are there any health risks associated with drinking your water/"

No perceived health risks	Unsure	Perceived health risks
76 (21.7%)	245 (69.8%)	30 (8.5%)