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Impact of receipt of private well arsenic test results on maternal use of contaminated drinking water in a U.S. population

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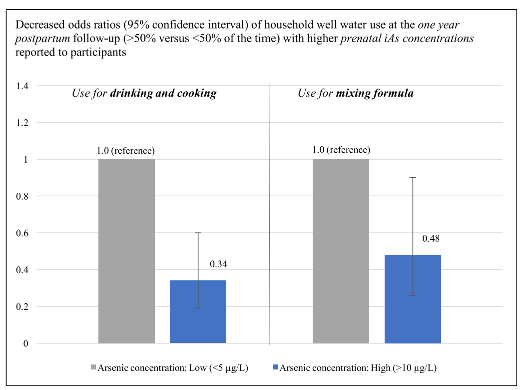
HIGHLIGHTS

- Receipt of well water iAs >10 μg/L reduced maternal water use.
- Receipt of well water iAs between 5 and 10 μg/L did not reduce water use.
- Private well testing during pregnancy should be prioritized.

GRAPHICAL ABSTRACT



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ABSTRACT

Exposure to inorganic arsenic in drinking water has known cancer and non-cancer health effects. However, no prior studies have addressed response to well water testing for arsenic during pregnancy, a time of known heightened risk perception. Using a US pregnancy cohort, we assessed the impact of receiving well water arsenic test results on subsequent use of arsenic-contaminated tap water. Study participants were 24–28 weeks' gestation at study entry and reported living in a residence served by a private, unregulated well. Upon enrollment participants provided a tap water sample which was tested for arsenic using ICP-MS. During pregnancy and every four months after, participants were asked their extent of tap water use for drinking, cooking and mixing infant formula. Logistic regression was used to estimate the odds of tap water use at one year post-partum in relation to baseline tap water use and arsenic concentration. Compared to those who used tap water <50% of the time, mothers who reported using tap water for drinking and cooking >50% of time in their prenatal questionnaire had 8.54 times the odds of using their tap water at 1-year postpartum (95% CI: 5.37, 13.60). After adjusting for frequency of prenatal tap water use, mothers were less likely to use tap water for drinking and cooking (OR = 0.34, 95% CI: 0.19, 0.60) and for mixing formula (OR = 0.45, 95% CI: 0.24, 0.86) if the high arsenic concentration (>10 μg/L) was known to them. Our findings suggest that providing well water test results during pregnancy may reduce subsequent maternal use of iAs contaminated tap water for drinking, cooking, and mixing infant formula. Public health implications are discussed.

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1. Introduction

The recent public health crisis in Flint, Michigan focused attention on children's vulnerability to the adverse health consequences of exposure to lead in drinking water and the importance of proper enforcement of existing environmental regulations such as the Environmental Protection Agency (EPA)'s Safe Drinking Water Act (SDWA) (Hanna-Attisha et al., 2015). However, the SDWA applies only to water systems serving 15 or more households or 25 or more people (US EPA, 2015). Thus, there is no regulatory oversight protecting children and their families who rely on private wells or small private water systems for their drinking water- a population encompassing approximately 43 million primarily rural U.S. residents and one in every seven U.S. households (Maupin et al., 2014; Zheng and Flanagan, 2017). This disparity in environmental protection and the resultant public health vulnerability are exemplified in northern New England, where widespread contamination of bedrock wells with naturally occurring arsenic is now recognized, 40–50% of the population is reliant on unregulated private water systems, and compliance with periodic well testing is low (Ayotte et al., 2012; Flanagan et al., 2015). Inorganic arsenic, a tasteless and odorless metalloid, has known cancer and non-cancer health effects and, like lead, it poses unique health risks to children (Naujokas et al., 2013; Rahman et al., 2013; Smith et al., 2006; Vahter, 2008).

In the absence of regulatory authority, public health entities in arsenic-affected communities have focused on motivating well owners to test for arsenic, and to reduce their exposure if indicated. Research on well owner's testing and treatment behaviors has identified influencing factors, such as health literacy (e.g., knowledge of harmful effects of exposure to arsenic or how to determine if well water is arsenic-contaminated), economic factors (e.g., price of testing and treating arsenic in well water), psychological factors (e.g., being overly optimistic or complacent about well water quality), and situational factors (e.g., lack of time) (Chappells et al., 2015; Flanagan et al., 2015; Flanagan et al., 2016). However, we found no prior studies specifically addressing response to well water testing in pregnancy, a time of known heightened risk perception (Oken et al., 2003). Recognizing that the developing fetus and infant are particularly vulnerable to the adverse health effects of inorganic arsenic exposure, we sought to understand the impact of receiving well water arsenic test results during pregnancy on subsequent maternal consumption and use of tap water (Farzan et al., 2013).

As shown in Appendix 1, exposure to iAs from contaminated bedrock wells is a health concern throughout NH (Ayotte et al., 2012). Launched in 2009, the New Hampshire Birth Cohort Study (NHBCS) has been characterizing arsenic exposure in mothers and their babies, and investigating maternal and child health effects. Pregnant women who report use of a private well are recruited during their second trimester and prospectively followed through delivery, with continued follow-up of their children out to 5 years of age. From this ongoing cohort study, we utilized the prenatal well water arsenic test results and self-reported estimates of tap water use obtained from participants at study entry as baseline information to compare to self-reported maternal tap water use at 1-year postpartum. We hypothesized that at the infant's 1-year follow-up, the higher the arsenic concentration in the private well water, the less likely the mother used the well water for drinking, cooking and mixing infant formula.

2. Methods

2.1. Study population

Data used in this study were derived from participants in the NHBCS. As described previously, study participants were recruited from participating NH obstetric clinics, and were eligible for enrollment if they reported using a private water system, were between 24 and 28 weeks' gestation, English speaking and between 18 and 45 years of age (Farzan et al., 2013; Gilbert-Diamond et al., 2011). The study was reviewed and approved by the Committee for the Protection of Human Subjects (CPHS) at Dartmouth College.

2.2. Home tap water sampling

Upon enrollment, women provided a water sample from their private well taken from their kitchen tap. If their well water was filtered, they were asked to provide both filtered and unfiltered water samples. Water samples were stored at −20 °C or below and analyzed for arsenic concentration by high resolution inductively coupled plasma mass spectrometry at the Dartmouth College Trace Element Analysis (TEA) Core as detailed in prior publications (Carignan et al., 2015; Farzan et al., 2013; Gilbert-Diamond et al., 2011). All arsenic in home tap water obtained from private wells was assumed to be inorganic arsenic (Meacher et al., 2002; NRC, 1999).

All participants received a written report by mail containing the actual measured concentration of iAs and the interpretation of this result as per the EPA regulatory limits. Participants with well water iAs concentration greater than the EPA's maximum contaminant level of 10 μg/L were contacted by telephone, and provided with educational materials about arsenic and health risks and recommendations for remediation prepared by the NH Department of Environmental Services (DES). All participants were given the NH DES telephone number to call if they had questions.

2.3. Questionnaires

Enrolled participants were asked to complete a baseline (prenatal) questionnaire, which included questions about sociodemographic characteristics, general health history, reproductive history, and health-related habits (including smoking or alcohol use before or during pregnancy). It further asked about water sources used for drinking and cooking, use of water filters and home tap water use. As part of the ongoing NHBCS, mothers were contacted by mail at 2 weeks postpartum and by phone at 4 months, 8 months, and 1 year postpartum for updated information about their treatment and use of home tap water for drinking, cooking and mixing infant formula.

2.4. Study population and outcome assessment

2.4.1. Study population

Water samples were tested in batches, and thus, participants could have received their water test results anywhere from antepartum to about 4 months postpartum. In our analysis, we used responses to the 1-year follow-up telephone survey to assess for changes in home tap water use to allow an adequate time for participants to alter their water use behavior after receiving their water test results. Our two outcome variables were: (1) frequency of home tap water use for drinking and cooking at the 1-year follow-up and (2) frequency of home tap water use for mixing infants' formula at the 1-year follow-up. Accordingly, we created two subsets for analysis to examine the two outcome variables respectively. The steps for participants' inclusion in our analysis are illustrated in the Appendix 2.

2.4.2. Home tap water use for drinking, cooking, and mixing formula at prenatal and the 1-year follow-up

At baseline, participants were asked to respond to the question: "Overall, what percentage of the water you use for drinking and cooking comes from your home tap water?" The five response categories were: "none/hardly any", "<25%", "25–50%", "50–75%" and "75–100%". At the 1-year follow-up survey, the question was repeated with the same five response categories. We recoded the five response categories into two categories, i.e., "none/hardly any - 50%" and "50–100%".

At the 1-year follow-up survey, if participants used formula and mixed it with water, they were asked about the percentage of home