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Health Protective Behavior Following Required Arsenic Testing under the New Jersey Private Well Testing Act

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Abstract

Exposure to naturally occurring arsenic in groundwater is a public health concern, particularly for households served by unregulated private wells. At present, one of the greatest barriers to exposure reduction is a lack of private well testing due to difficulties in motivating individual private well owners to take protective actions. Policy and regulations requiring testing could make a significant contribution toward universal screening of private well water and arsenic exposure reduction. New Jersey's Private Well Testing Act (PWTA) requires tests for arsenic during real estate transactions; however, the regulations do not require remedial action when maximum contaminant levels (MCLs) are exceeded. A follow-up survey sent to residents of homes where arsenic was measured above the state MCL in PWTA-required tests reveals a range of mitigation behavior among respondents (n=486), from taking no action to reduce exposure (28%), to reporting both treatment use *and* appropriate maintenance and monitoring behavior (15%). Although 86% of respondents recall their well was tested during their real estate transaction, only 60% report their test showed an arsenic problem. Treatment systems are used by 63% of households, although half were installed by a previous owner. Among those treating their water (n=308), 57% report that maintenance is being performed as recommended, although only 31% have tested the treated water within the past year. Perceived susceptibility and perceived barriers are strong predictors of mitigation action. Among those treating for arsenic, perceived severity is associated with recent monitoring, and level of commitment is associated with proper maintenance. Mention of a treatment service agreement is a strong predictor of appropriate monitoring and maintenance

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behavior, while treatment installed by a previous owner is less likely to be maintained. Though the PWTA requires that wells be tested, this study finds that not all current well owners are aware the test occurred or understood the implications of their arsenic results. Among those that have treatment installed to remove arsenic, poor monitoring and maintenance behaviors threaten to undermine intentions to reduce exposure. Findings suggest that additional effort, resources, and support to ensure home buyers pay attention to, understand, and act on test results at the time they are performed may help improve management of arsenic water problems over the long term and thus the PWTA's public health impact.

Keywords

private well; arsenic; New Jersey; water testing; water treatment; regulation

1. Background

Arsenic is naturally occurring in groundwater across the United States and worldwide. Chronic exposure to arsenic through drinking water is associated with various adverse health effects including cancers, cardiovascular disease, lung disease, and diminished child IQ.[1,2] Although users of public water systems benefit from the federal Safe Drinking Water Act and its regulatory oversight ensuring their drinking water meets government standards for arsenic and other contaminants, the 45 million Americans who rely on private well water are excluded from these protections at home.[3,4] Monitoring and maintaining the quality of drinking water remains the responsibility of individual well owners. The "private" designation of water sources supplying fewer than 25 people or 15 households spares individuals the regulatory burden of compliance,[5] while forgoing equal assurances of safe drinking water. Exceptions for individual household water supplies from drinking water regulation appear to be the norm worldwide where such laws are enforced, despite consistent evidence of poor water quality and increased health risks from private sources.[6–8]

The exact portion of the over 13 million U.S. households dependent on private well water[9] who are affected by arsenic, or the health and economic costs associated with that exposure, is unknown without a regulatory monitoring system in place. However, the probability of arsenic occurrence at regional and local scales can increasingly be predicted by geostatistical modeling;[10,11] a recent study estimates over 2.1 million Americans are drinking from wells with arsenic above the 10 μg/L federal standard.[12] A likely greater number drink from wells above the more protective standard of 5 μg/L, in effect for the state of New Jersey since 2006. Nevertheless, high degrees of spatial heterogeneity mean the presence and concentration of arsenic in individual wells can only be determined by a specific water test. Therefore, every well must be tested.

In the absence of regulations, individual protective behavior is essential to exposure reduction, yet the reasons private well owners test or do not test their water are often complex, with additional challenges in the case of arsenic.[13–18] As a result, a majority of households, including those located in at-risk areas, have not tested their wells for arsenic and are unaware of their exposure risk.[13,19,20] Community campaigns to encourage private well testing often have limited success,[21–23] and socioeconomic disparities in exposure likely arise from differing rates of testing participation.[14,16] Given the challenges in motivating individual private well owners to act, there is potential for policy and regulations to make a significant contribution towards universal screening of private well water quality.[24]

With its Private Well Testing Act (PWTA), New Jersey is one of only two states in the United States, the other Oregon, to require testing of private well water for arsenic during real estate transactions.[24] Between September 2002 and April 2014 the PWTA has generated over 43,000 well tests for arsenic in the counties where it is required. However, testing only acts as a screening tool. The PWTA is a right-to-know law and has no requirement that protective action be taken, only that the test occur and that both parties certify at closing that they have received and reviewed the water test results. Nevertheless, the law provides a model for practical and feasible state-level policy and regulatory action, in the absence of other regulations, to ensure that more private wells are tested for arsenic.

After arsenic is found in a well, a household must then decide on further action to reduce exposure – treatment, use of bottled water, or no action. Follow-up surveys to participants of voluntary well testing programs in other states find that a third to a half of households notified of high arsenic in their water may not be acting to reduce their exposure,[25,26] suggesting that protective behavior even among informed well owners is not guaranteed. The specific effect of PWTA-required testing during home purchase, as compared to voluntary testing,[10] on subsequent protective actions among those with arsenic exceedances, is still unknown. Despite anecdotal stories that the pressure of the home sale prompts negotiations for installation of corrective treatment, there is no quantifiable evidence available to confirm this. Findings from a random sample survey of private well households in northern New Jersey suggest that owners of wells tested under the PWTA may frequently forget or misremember arsenic test results, are more likely to not know what kind of water treatment they are using, and do not report better maintenance or monitoring of treatment than those who had voluntarily tested their well water.[19,27] This suggests challenges to reducing exposure remain even when testing is required.

A survey of well owners with arsenic above the NJ standard of 5 μg/L as identified through PWTA-required testing was conducted to estimate the proportion acting to mitigate arsenic exposure, the proportion appropriately monitoring and maintaining their treatment systems, and to investigate the factors that influence these mitigation behaviors. Understanding the arsenic-mitigation behavior among this population will help to evaluate the impact of the PWTA, aid the development of public resources to support well owners with their exposure reduction needs, and inform the design of future private well testing and treatment programs and policies.

2. Methods

2.1 Study population

Over one million people (11% of the population) in New Jersey rely on private well water for drinking.[3] Only 25% of private wells are estimated to have been tested through the

PWTA in the years since 2002, due, in part, to the pace of housing turnover.[19,27] The PWTA requires testing untreated well water for arsenic in the12 counties in the northern half of the state where arsenic concentrations as high as 250 μg/L are naturally occurring in the bedrock aquifers of the Newark Basin (Figure 1).[28] Of the private wells tested, 8.9% have exceeded the state arsenic standard for drinking water and arsenic has been found more frequently than any other contaminant.[29] From September 2002 through March 2014, there were 3,476 unique wells found with arsenic values greater than 5.0 μg/L. Public and commercial properties, based on property tax records, and several addresses which had been randomly selected for a previous mailed survey on arsenic testing and treatment in 2014[27] were excluded from selection. The final sample of 1,500 addresses included all wells with ≥25 μg/L arsenic (n=175), all wells with 10–25 μg/L (n=872), and an approximately 20% random selection of all wells with 5–10 μg/L (n=453). The median well arsenic value of the selected addresses was 12 μg/L, and median tax-assessed property value was $456,650. Specific test results are maintained as confidential and are not publicly shared as a condition of the Act.

2.2 Data collection

Data were collected via self-administered mailed questionnaire, adapted from surveys used for arsenic-affected private well users in Wisconsin[30] and Maine[18] and reviewed by key stakeholders in New Jersey for content validity. Questions covered arsenic testing experiences, water treatment practices, and basic demographic information. A series of statements based on health behavior theory with Likert scale responses were included to explore the relative influence of psychological beliefs on mitigation behavior outcomes. Survey items were categorized into psychological constructs that may explain arsenic mitigation behavior (Table S1), as outlined by the Health Belief Model: Perceived Susceptibility – feelings of personal vulnerability to arsenic exposure; Perceived Severity – feelings on the seriousness of consequences of arsenic exposure; Perceived Benefits – perceived effectiveness of actions to reduce exposure; Perceived Barriers – feelings on the obstacles to reduce exposure; Self-efficacy – level of confidence in one's ability to reduce exposure; and Cue to Action – advice to reduce exposure from a local authority.[31] This model was modified with the additional factor of "Commitment," or the feeling of obligation to reduce arsenic exposure, taken from the RANAS model of integrated health and social psychology theories[32] because it has been found to be a significant predictor of arsenic mitigation behavior in Bangladesh.[33,34]

Contact strategy was based on Dillman's Tailored Design Method,[35] employing repeated contact to increase the survey response rate. Survey materials were addressed to the current owner listed in the NJ property tax records, "or current resident." Selected addresses (n=1,500) were mailed a letter notifying of the forthcoming survey several days before receiving a cover letter, a coded questionnaire, and a pre-stamped return envelope. Enclosed with the survey was a $2 bill. Such a "token of appreciation" provided at the time of survey delivery has been shown to increase participant response more effectively than post-paid incentives contingent on participation.[36,37] The deadline for returning the survey was set four weeks out. A week after the surveys were mailed all addresses were sent a thank you/ reminder postcard, and several weeks later non-responding addresses were mailed a follow-up reminder letter, extending the deadline for participation by another month. The study protocol and survey instrument were approved by the Institutional Review Board of Columbia University.

2.3 Data analysis

Descriptive statistics and multivariate analyses were performed using Stata/IC 14.2. Individual survey items on a Likert scale of 1 (strongly disagree) to 6 (strongly agree) were averaged to build composite scales of psychological constructs for use in multivariate analyses. Confirmatory factor analysis (CFA) was performed to assess the model fit of each scale alone and together in a single model (Table S1). Each of the scales exhibited adequate internal consistency ($\alpha \geq 0.70$) and CFA model statistics indicated adequate fit for each scale and the overall model, following accepted criteria (CFI>0.93, SRMR<0.08, RMSEA<0.08).[38] Two items were dropped from the Perceived Severity scale due to weak factor loadings (<0.40).

Spearman correlation analyses were performed to identify significant associations ($p<.05$) between primary outcomes and sociodemographic and psychological factors. The primary behavior outcomes include Mitigation, defined as reported use of arsenic treatment or avoidance of the water, i.e. reporting "rarely or never" using the well for drinking; Treating, defined as reporting use of a water treatment system specifically installed to remove arsenic; Monitoring, defined as having ever tested the treated water, compared to Recent Monitoring, having tested the treated water within the past year, the minimum frequency recommended; and Maintaining, defined as reporting that maintenance on the treatment system is performed "as recommended." Significant factors were retained for logistic regression analyses to estimate their effect on the odds of the primary outcome behaviors.

Additional explanatory variables selected for regression analyses include whether the respondent reported their well was tested during their real estate transaction (Recall test); whether they selected the correct range of the arsenic result for that test (Report correct level); whether they selected "arsenic" when asked whether the well test showed a problem for anything (Identify arsenic problem); how the respondent rated the difficulty of understanding their test report, on a scale of 1 to 5 from "very easy" to "very difficult" (Difficult understanding report); and whether they report having discussed their arsenic level with anyone outside the home (Discussed arsenic with somebody). Treatment system variables including the reported years since installation (System age), whether it was installed by a previous owner (Seller installed), and whether the respondent mentioned an ongoing vendor arrangement when describing their treatment maintenance process (Service agreement), were included in regression analyses as predictors of monitoring and maintenance only.

First, univariate models predicting the primary outcomes from these selected explanatory variables and the identified significantly associated sociodemographic and psychological factors were calculated. Then, separate multiple logistic regressions were calculated to identify the most influential of these explanatory, sociodemographic, and psychological factors within factor groups (models 1 and 2). Finally, a combined model including all significant factors of these previous regressions was computed to estimate the relative importance of significant predictors (models 3) on the outcome behavior. The combined regression models predicting mitigation and treatment were stratified by number of years since PWTA test, <8 or ≥8 years.

Sensitivity analyses were also conducted to assess potential non-response bias. Without known values for the target population available for comparison, one method to estimate nonresponse bias is to use extrapolation, based on the assumption that participants who respond less readily are more like non-respondents. For example, individuals who respond in later waves of a survey, i.e. after follow-up contacts, are assumed to have responded because of the increased stimulus and therefore expected to be similar to nonrespondents.[39] For this survey a follow-up letter was mailed near the initial deadline to respond, reminding recipients to participate and extending the time to return the survey by an additional month. Participants who returned the survey after the initial deadline were classified as "late responders" for comparison to the full sample.

3. Results

3.1 Characteristics of respondents

Out of the 1500 surveys mailed, 106 were undeliverable and 500 surveys were returned completed. The survey response rate among delivered surveys (n=1394) was 36%. Surveys returned from households now on public water supply (n=14) were excluded from analysis. Four surveys returned completed but with codes removed were retained in the sample for analysis but cannot be linked to PWTA test records.

Survey respondents were overwhelmingly home owners, had a median age of 51 years, and were highly educated; over 76% have a bachelor's degree (Table 1). Additionally, respondents had very high incomes; over half of participating households reported incomes greater than $150,000. Nearly half of households include at least one child under 18, while 10% of respondents live alone. Most households (85%) report that they rely on their well water for drinking from some to all of the time. While such characteristics among those who did not respond to the survey are unknown, the distributions of arsenic level and assessed property value among respondents reflect the overall selected sample and are not significantly different from non-responding households.

3.2 Testing recall and response

Selection for the survey was based on PWTA test results following real estate transactions which showed an arsenic concentration above 5 μg/L. Most respondents (86%) could recall that a well test occurred at that time (Table 2). Another 7% who did not recall a test occurred at that time reported that their water has been tested for arsenic since, while the remaining 7% are unaware that their well water has ever been tested. Although most recall the PWTA test occurred, only 60% of respondents report that their well test showed an arsenic problem. Only 30% of private well owners with arsenic levels between 5 and 10 μg/L whose wells were tested before the new NJ MCL went into effect in 2006 (n=47) identified an arsenic problem, compared to 60% of those with similar levels who purchased their home since 2006 (n=97).

Less than a quarter of respondents could accurately report the range of the arsenic concentration of their well (Table 2). Respondents were more likely to underestimate than to overestimate their arsenic concentration, although over half were not able to remember or answer. Yet, only a small portion of respondents (8%) reported that they had any difficulty understanding their water test results, while 31% said the test report was neither easy nor difficult to understand. Water treatment professionals and real estate agents were the most common party for homeowners to have discussed their arsenic test results with. Overall, 60% of all survey respondents reported that they had discussed their arsenic level with somebody outside their household while 87% of those who identified having an arsenic problem sought outside consultation. A significant portion of respondents were unable to select the highest level of arsenic they would consider safe (Table 2), many writing in that they did not know enough to make a choice. Half of survey respondents selected below 5 μg/L, the drinking water standard in New Jersey, while 17% indicated they considered concentrations above this level safe to drink.

3.3 Mitigation behavior

Nearly two-thirds of respondents indicated that they have treatment installed to remove arsenic from their water, almost evenly split between systems installed by a previous owner and systems installed by the current resident (Table 2). Another 8% of households indicate they drink from their well water “rarely or never” and thus can also be considered mitigating their exposure to arsenic, despite not using treatment. Thus, the remaining 28% of surveyed households are not acting to reduce their exposure to arsenic (Figure 2).

The most common reasons for not installing treatment were not being concerned about the arsenic level (27%), drinking bottled water to reduce exposure (11%), and not knowing what kind of treatment to get (9%). The hypothetical situations most commonly selected to prompt treatment installation were: if a test showed their arsenic level had increased above what it is now (48%), if they learned that arsenic in their drinking water could increase their risk for cancer (34%), and if a doctor recommended they treat their water (30%). Many (31%) also said that they would treat their water to remove arsenic if it caused a change in the taste, smell, or appearance of their water; unfortunately, arsenic is tasteless, colorless, and odorless.

Among those who reported having arsenic treatment installed (n=308), 47% report that at least part of their water treatment system came with the home when they purchased it (Table 3). The median age of treatment systems was seven years, and the median cost to install among those who could provide an estimate was $3000. Arsenic treatment systems were overwhelmingly whole-house, rather than point of use. Most respondents (74%) with arsenic treatment report that the treated water has been tested at least once since installation, although only 31% indicated their most recent test was within the past year. Just over half (57%) of well users with treatment report that their systems are maintained as recommended, while 18% report that maintenance has rarely or never been performed. When asked to describe their treatment maintenance process, only a quarter of treating households mentioned regular service visits by an outside company. Three respondents specifically commented that although an arsenic system came with their home at purchase, the cost to replace treatment tanks was too expensive and so they have disconnected the treatment or have not replaced the media since moving in. Despite the high household incomes in this sample, over half (54%) of all survey respondents agreed with the statement “treating my water is too expensive.”

3.4 Correlation analyses

Well arsenic level as measured in the most recent PWTA test is positively and significantly associated with both mitigation and treatment use ($p<0.001$); 80% of survey respondents with arsenic > 25 µg/L are taking mitigation action, while only 62% of those with 5 to 10 µg/L are doing so. Generally, other sociodemographic characteristics (Table 1) are not significantly associated with primary outcomes in this sample; however, both mitigation and use of arsenic treatment are significantly negatively associated with number of years lived in the home ($p<0.001$), while water treatment is negatively associated with age ($p<0.05$) and positively associated with having a bachelor’s degree ($p<0.01$). Associations between sociodemographic characteristics and the monitoring and maintenance behaviors among treating households are not statistically significant.

All psychological factors based on the modified health belief model are significantly associated with mitigation and use of arsenic treatment ($p<0.001$). Among those using treatment, only self-efficacy and commitment are significantly associated with having ever tested treated water, while perceived severity, perceived benefits, and perceived barriers are also significantly associated with having tested treated water within the past year. All factors except perceived susceptibility and cue to action are significantly associated with maintaining treatment protocols.

3.5 Predictors of mitigation behavior

Significant predictors of taking mitigation action (either treating or avoiding water) in unadjusted regression models (Table 4) include identifying an arsenic problem, having discussed their arsenic level with somebody outside their household, the actual arsenic concentration of their well, and the number of years lived in the home. In multivariate models only identifying an arsenic problem and having discussed arsenic with somebody (Table 4, Model 1), and the behavioral factors perceived susceptibility, perceived barriers, self-efficacy, and cue to action remained significant (Table 4, Model 2). In an adjusted model stratified by years in the home (Table 4, Model 3), having discussed arsenic with somebody (OR=3.83) is an important predictor of mitigation among those who purchased their home less than 8 years ago, while identifying an arsenic problem (OR=5.54) is the most significant predictor of mitigation among those who have lived in their home for longer. Perceived barriers (OR=0.65), and self-efficacy (OR=1.36) are also significant predictors of mitigation, only among those living in their home for at least 8 years.

For arsenic treatment use specifically, identifying an arsenic problem and perceived susceptibility remain significant predictors in stratified adjusted models (Table 5, Model 3). For respondents who have lived in their home less than 8 years, having a bachelor’s degree becomes highly significant (OR=11.51), an effect not seen in the mitigation models. The average marginal effect of a bachelor’s degree among this group is a 21% increased likelihood of treatment use (p<.001). For respondents who have lived in their home at least 8 years, the effect of education is not significant. Instead, commitment (OR=1.94), arsenic concentration, perceived barriers (OR=0.60), and self-efficacy (OR=1.47), are significant predictors of treatment use.

Among those treating for arsenic, having ever tested the treated water is significantly predicted by self-efficacy and having discussed arsenic with somebody (Table S2, Model 3). If the homeowner has discussed their arsenic level with an outside person, they have nearly 3 times greater odds of having ever tested their treated water (95% CI: 1.50–5.84). When the outcome is narrowed to testing the treated water within the past year, only perceived severity (OR=1.35) and mention of a treatment service agreement with an outside company (OR=1.86) remain significantly associated with recent monitoring in an adjusted model (Table 6, Model 3).

Only 57% of well owners treating for arsenic report that maintenance on their treatment system is performed as recommended. The party responsible for installing the treatment strongly determines whether the current homeowner will continue maintenance. For example, a current resident is 15% less likely to be properly maintaining a treatment system if it was installed by the previous owner (p<0.01). However, in a model adjusting for psychological factors, only level of commitment (OR=1.64) and whether the respondent mentioned a treatment service agreement (OR=3.5) are significant predictors for proper maintenance (Table 7, Model 3).

3.6 Non-response sensitivity analysis

Approximately 21% of participants returned the survey after the initial deadline and were therefore classified as “late responders” for comparison to the full sample. There are no significant differences between this subset and the full sample on any socio-demographic characteristics or well arsenic concentration. A comparison of responses for key variables (Table S3) reveals that late responders are significantly less likely to report that their well has an arsenic problem (47.6% vs. 59.9%, p<.05), but differences on the primary outcomes of mitigation, treatment use, and maintenance and monitoring are not statistically significant.

4. Discussion

4.1 Most take protective action after PWTA testing

Since 2002, the PWTA has required tens of thousands of private wells in northern New Jersey to be tested for arsenic. Previous research has suggested that 4 out of 5 households with high arsenic who have not yet been required to test under the PWTA are likely unaware of their water problem and remain exposed.[19] While the PWTA only requires a test occur, this study suggests that a majority of home buyers notified their well has arsenic levels above the NJ drinking water standard have acted to reduce their exposure. Being aware that a test occurred and that the results showed an arsenic problem are important predictors of arsenic mitigation action. The fact that some respondents were unaware of the PWTA testing (14%) or their specific arsenic result (79%) suggests that there is room for improvement in communicating test results to home buyers so that the implications are understood.

Perceived susceptibility to arsenic contamination remains a significant predictor of mitigation action after adjusting for other significant psychological and situational factors; however, well owners who have been living in their home longer appear more entrenched in their original mitigation decisions as perceptions of barriers such as cost, time, effort, and beliefs about self-efficacy are also strong predictors of action. Among more recent home buyers there may be a socioeconomic effect on treatment use; private well owners with a bachelor's degree have significantly greater odds of having arsenic treatment installed than those with less education, a relationship between education and treatment previously observed in New Jersey and elsewhere.[14] However, education does not seem to have a significant effect on mitigation in general. This echoes a study from Maine which found no relationship between socioeconomic measures and mitigation, but found that among those taking action, higher educated and higher income well owners were more likely to install treatment while lower educated and lower income well owners were more likely to rely on bottled water to reduce their exposure.[18] This divergence may stem from the prohibitive upfront costs of installing treatment, despite it being more cost-effective over the long term than purchasing water for households of more than one person.[40] The ratio of arsenic treatment to bottled water use among mitigating households is much higher here in New Jersey (7.9 to 1) than in Maine (1.2 to 1),[18] perhaps reflecting the higher income population or that arsenic treatment options are more readily available, more affordable, or both.

Importantly, arsenic concentration remains a significant factor in mitigation decisions[18] as suggested by increased rates of mitigation at higher arsenic levels. However, it should be noted that self-reported mitigation actions do not guarantee exposure reduction. Households that rely on bottled water or point-of-use treatment may remain exposed through occasional drinking and cooking with untreated water.[41,42] Furthermore, exposure can persist because of ineffective or failing treatment systems.[18,41,43,44]

4.2 Monitoring and maintenance behavior could undermine treatment intentions

Treatment units can be ineffective for arsenic due to the geochemistry of the well water, or fail from improper maintenance. Without regular monitoring, this failure and the resulting exposure can go unnoticed by well-intentioned homeowners. In Maine, 10 of 68 treatment systems tested failed to deliver water with arsenic below the federal MCL of 10 μg/L.[18] In New Jersey, 4 of 22 treatment systems tested in one study,[16] and 7 of 65 systems tested in another focused on a township which requires whole-house dual tank arsenic treatment systems, failed to deliver water below 5 μg/L at the kitchen sink. In all cases the homeowners were unaware. Private well owners treating for arsenic or any other contaminant are encouraged to test their treated water yearly to ensure the system is functioning, but consistent monitoring at that frequency is rare, as further observed in this study. Perceived severity of the adverse effects of arsenic and having an arrangement for regular servicing of the treatment system emerge as significant predictors of recent testing among respondents.

Along with commitment to decreasing exposure, having a service agreement is the most significant factor predicting proper treatment maintenance. Maintenance contracts are not required with the purchase of water treatment systems in New Jersey; in fact, the entire private water treatment sector is unregulated. While many survey respondents described following a regular testing schedule on their own and then arranging for treatment maintenance as needed, those who report receiving regularly scheduled contacts or visits from an outside company also report better monitoring and maintenance behavior. However, few treating households (27%) mention such an arrangement, although it is significantly more common among well owners who more recently moved into their home.

The 57% of treating households in this study reporting that their system is being maintained as recommended is much lower than the 79% found in the Maine follow-up of voluntary testing where the majority of treatment installed was point-of-use rather than whole-house, and nearly all systems were installed by the current owner.[18] In this study, treatment installed by a previous homeowner, as half of the systems reportedly were, is significantly associated with reduced odds of proper maintenance, although this effect is no longer statistically significant after adjusting for psychological factors. A quarter of those who said their system was installed by the previous owner report that maintenance has rarely or never been performed, compared to 10% among those who purchased the treatment themselves. Current homeowners who did not manage the treatment installation may not understand how the system works or should be maintained; here, they report significantly lower levels of self-efficacy and commitment. Respondents with seller-installed arsenic treatment systems are also significantly more likely to report that they “don’t remember” the arsenic level of their well revealed by the PWTA test. Previously installed systems are more common among recent home purchases, which could reflect a trend of more successful negotiation for new systems on the part of educated buyers or that treatment had already been installed after earlier arsenic screening. Either way, this trend suggests that effective maintenance of existing arsenic treatment systems will be a growing challenge.

That so many households (54%) in such a high-income sample would consider arsenic treatment too expensive is concerning, considering that most arsenic-affected populations on private well water are likely less affluent than this population. Median annual household incomes in New Jersey towns where at least 10 wells have been tested for arsenic under the PWTA range from $60,229 to $171,747,[45] and the median tax-assessed value of properties selected for this survey is $456,650. While the PWTA does not include requirements for treatment, it was assumed that a “failed” test would be resolved through negotiation between buyer and seller since prospective buyers could insist on remediation as a condition of the purchase. While that may be the case for a number of surveyed households, and is perhaps why nearly half of arsenic treatment systems in this sample were installed by the previous owner, the costs of installation are a one-off payment compared to frequent and often expensive maintenance depending on the water arsenic concentration, water use of the home, and treatment media used. Respondents describe needing to replace the media in their arsenic treatment tanks every 2–3 years, at around $1000 to $2000 each time, on top of other water treatment needs including annual water tests which can run up to hundreds of dollars.

These ongoing costs can be an additional barrier to mitigation; more than one respondent in this survey mentioned that they have “switched off” the arsenic system because they can’t afford to replace the media. Although New Jersey does offer an interest-free loan program for drinking water improvement through the Housing & Mortgage Finance Agency,[46] it cannot be used to pay for ongoing maintenance costs.

4.3 More than a quarter of exposed households do not act after testing

The portion of surveyed households not taking action to reduce arsenic exposure (28%) in this study is similar to the rates found by surveys in Maine (27%)[18] and Wisconsin (40%)[25] that followed-up with voluntary testing program participants, and a recent Minnesota survey (35%) that followed up on testing after new well construction.[47] Outside of the United States, a study of a well screening and education intervention in Bangladesh, where tens of millions have been chronically exposed to arsenic,[48] found over a third of participating residents did not switch to an alternative water source.[49] Together these studies confirm that a significant portion of private well users do not act on arsenic testing results. The expectation that screening programs or requirements will cause individuals to take subsequent protective action on their own is only partially true. For the full benefit of universal screening leading to exposure reduction, it will be necessary to address the psychological and situational barriers to mitigation action after testing among the affected populations.

While we don't fully understand why the rates of non-action are so similar across populations and across testing conditions, in this particular New Jersey population we see the psychological differences most clearly between the 15% of respondents who could be considered "doing everything right," i.e. treating their water, maintaining as recommended, and have tested in the past year (Figure 2), and the 28% of respondents who are not taking any actions to reduce exposure. The differences in all psychological factors between these "super-actors" (n=74) and "non-actors" (n=138) are highly significant ($p<.001$) (Table S4). Super actors are also more likely to have a bachelor's degree and higher household income. However, most respondents (57%) fall in between these extremes of action; they (or a previous owner) took some action to reduce arsenic exposure but they may not be practicing the maintenance and monitoring behavior necessary to be confident in its effectiveness.

Only 41% of non-acting respondents report their well has an arsenic problem, the rest either do not believe they have a "problem," or are unaware of the arsenic level in their water, both reflected in low perceived susceptibility. Some misremembering may be due to confusion over the relevant drinking water standard for arsenic. Just before the PWTA went into effect in 2002, the federal government adopted a new arsenic standard of 10 μg/L, replacing the previous 50 μg/L standard. In late 2004, the state of New Jersey adopted a more protective standard of 5 μg/L. Both new standards, enforceable only for public drinking water systems, went into effect in January 2006. Although these standards had been adopted prior to 2006, it may not have been clear to private well owners who tested before then; PWTA laboratory reports from the time used the old standard as a reference value for results, with a small footnote mentioning the new federal standard. Current homeowners who last tested their well when purchasing their home before 2006 may not be aware that their satisfactory arsenic result at that time would be considered a "problem" now. The year of the most recent PWTA test is a highly significant predictor of identifying an arsenic problem and mitigation action (p<.001); the longer ago the test, the less likely a problem is identified or action was taken. When excluding tests before 2006 the effect of the test year is no longer significant.

4.4 Study limitations

Although survey research into behavior necessarily relies on self-reporting, and therefore data quality depends in part on respondents' willingness and ability to provide accurate answers,[50] it is often the most appropriate method to obtain personal information not available elsewhere.[51] There is no requirement to act on PWTA test results, thus assessment of mitigation behavior requires collecting data from affected individuals themselves, even if they are reporting events from many years ago. A thorough assessment of current treatment use and actual arsenic exposure would require on-site inspections and water sample collection,[52] which were beyond the means of this study.

Despite efforts to minimize and evaluate survey non-response, it is possible that the 486 participants do not fully represent the overall population they were drawn from. Although there is no socio-demographic data available for non-responding households, we find no significant difference in the distribution of assessed property value, a proxy measure for other socioeconomic measures, or recent arsenic test results, among responders and non-responders. The sensitivity analysis comparing late responders to the full sample also shows no difference in sociodemographic characteristics or primary outcomes, although it suggests that non-responders, if more like late-responders, may be less likely to identify having an arsenic problem than survey respondents.

Despite similar rates of action and non-action in other surveyed communities, the findings in this population may not be applicable to other areas of the United States or elsewhere where well water regulations, public resources, and mitigation options differ considerably from those in New Jersey. Furthermore, since this northern New Jersey area is generally very educated with a high household income, this may not be the best sample to further explore socioeconomic influences on the target behaviors; there was little effect among this population. Additionally, less than 2% of survey respondents here are renters, and only 2 of 7 renters identify an arsenic problem in their well despite concentrations ranging from 10.0 to 39.5 μg/L. Although the PWTA applies to rental properties and landlords are supposed to provide renters with a well test report when they sign a lease, a shortcoming of the law is that there is no record-keeping or enforcement system. The total number of rentals that should be regulated under the PWTA is unknown, and many required tests may not be happening. Potential survey non-response and exposure reduction among this population is therefore difficult to assess.

Despite its limitations, this study is the only investigation into arsenic mitigation behavior among households required to test during real estate transactions, its findings are supported by previous studies of arsenic mitigation behavior, and it identifies several factors which contribute to persistent exposure among a rare population that has been universally screened as a result of state legislation.

5. Conclusion

Regulations to require testing such as the Private Well Testing Act can make a significant contribution towards universal screening of private well water quality. While this study finds the PWTA leads to subsequent mitigation action among most households with an arsenic issue, many well owners are not aware that a test occurred or understand the implication of their arsenic results. The fact that so many do act to reduce exposure is an achievement of the legislation to require well water testing; however, as long as there is no requirement for remediation a significant portion of those affected will not take action due to a combination of situational and psychological factors.

Among those that have treatment installed to remove arsenic, poor monitoring and maintenance behaviors, especially among prior-installed systems, threaten to undermine intentions to reduce exposure. The ongoing costs of treatment may contribute to this, as could other barriers to the self-efficacy and commitment beliefs required to manage these ongoing responsibilities or to arrange for a service contract. Most affected households fall in this middle range of behavior where there may be an interest or intention to reduce exposure, even if monitoring and maintenance behavior are not perfect. Among those who bought their home many years ago and have not taken mitigation action since, perceived barriers to treatment are stronger and interventions to change beliefs and behavior now are more likely to face additional challenges.

Notably, most private wells in New Jersey have still not been tested under the PWTA. This requirement to test at home purchase provides an opportunity for upfront intervention, before mitigation decisions are made. Additional effort, resources, and support to make sure that new home buyers pay attention to, understand, and act on test results at the time they are performed could lead to higher mitigation rates and help to instill the commitment required to manage arsenic water problems over the long term, thereby more effectively reducing population exposure and increasing public health impacts.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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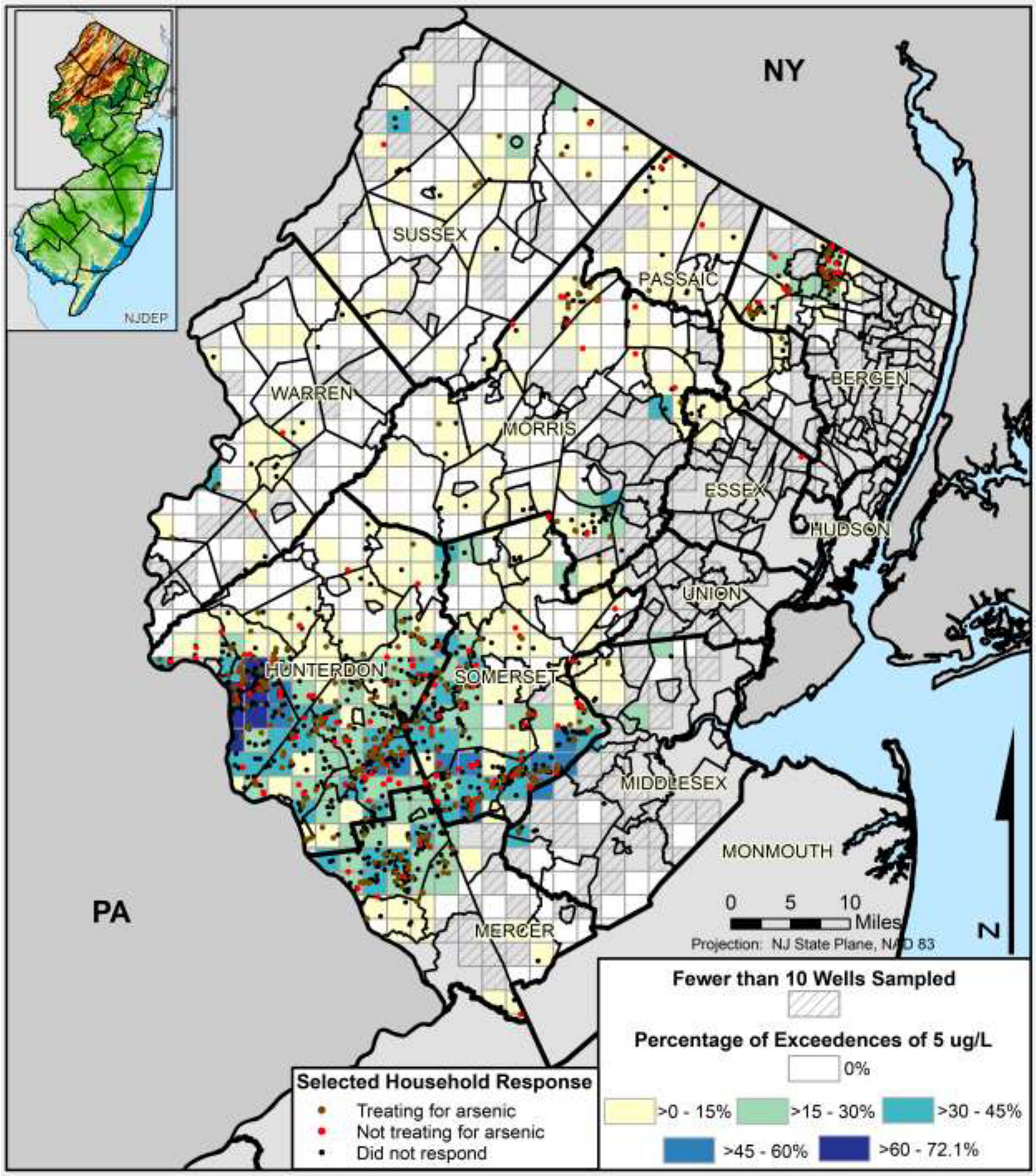

Figure 1:

Dots represent the location and reported treatment use among households mailed the survey. The grid represents the percentage of wells tested through the PWTA that exceeded the New Jersey MCL within 2×2 mile areas. The Newark Basin underlies areas of Mercer, Hunterdon, and Somerset Counties.

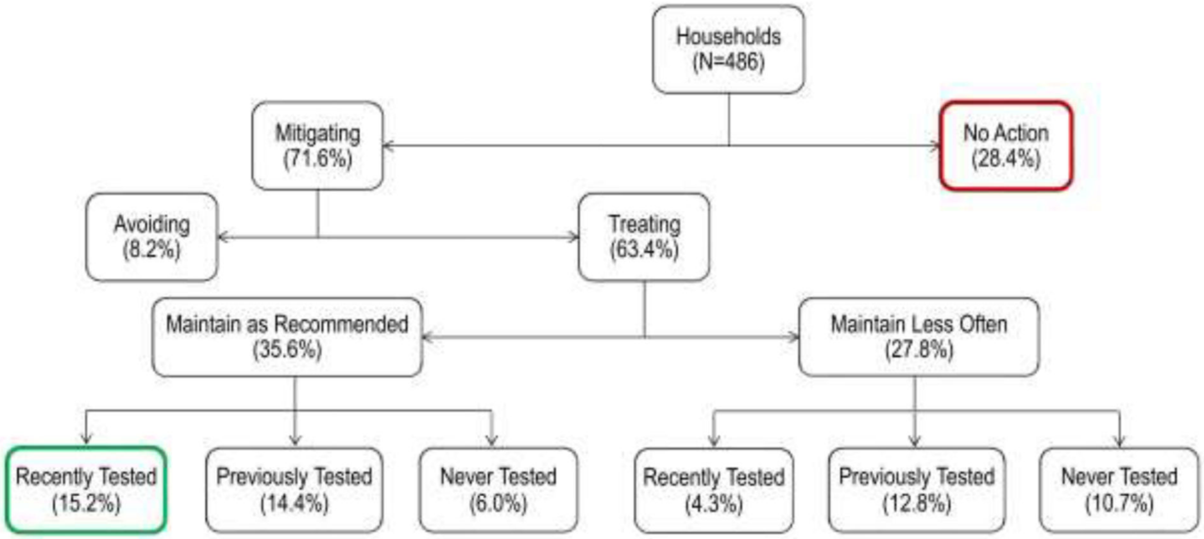

Figure 2:

Reported mitigation behavior among all survey respondents. Green box indicates the "super actors" who are appropriately maintaining and monitoring their treatment system; Red box indicates those taking no action to reduce arsenic exposure. Percentages represent respective portion of all households.

Table 1:

Characteristics of survey respondents with private wells (n=486)

Variable	Frequency
Home Owners	96.7%
Years in Home	Median 8, Range 0–55
Age	Median 51
18–44	23.9%
45–64	62.9%
65 and older	13.2%
Male/Female	54.6% / 45.4%
Education	
High school or less	5.1%
Some college	18.2%
Bachelor's degree	38.1%
Graduate Degree	38.6%
Household Income	
<$50,000	4.7%
$50,000 – 100,000	18.0%
$100,000 – 150,000	20.5%
$150,000 – 200,000	16.8%
> $200,000	40.0%
Children in Home	48.7%
Living Alone	9.5%
Water Use	
Mostly or Always	72.7%
Sometimes	12.2%
Rarely or Never	15.1%
PWTA Arsenic Measure[†]	
Less than 5 pg/L	3.9%
5 to 10 pg/L	29.9%
10 to 25 pg/L	53.5%
25 to 50 pg/L	10.8%
> 50 pg/L	1.9%

[†]Most recent PWTA test value if the property was sold more than once since 2002, and so could be less than 5 µg/L

Table 2:

Testing recall and response actions (n=486)

Variable	Frequency
Recall Test at Sale Occurred	85.6%
Not tested at sale, but tested since	6.8%
Report Test Showed Arsenic Problem	59.9%
Recall Arsenic Results	
Not able to answer	58.2%
Reported level range correctly	21.0%
Reported higher range	3.3%
Reported lower range	17.9%
Understand Test Results	
Very easy	30.7%
Easy	30.5%
Neither easy nor difficult	30.5%
Difficult	5.9%
Very difficult	2.4%
Have Discussed Arsenic Level With...[†]	
Real estate agent	24.7%
Testing lab representative	21.0%
Water treatment professional	36.6%
Local health department	3.1%
Neighbor	16.3%
Friend/Relative	15.6%
Plumber/Well driller	10.7%
Other	4.7%
None	39.5%
Highest Arsenic Level Consider Safe	
5 pg/L or less	52.5%
5 to 10 pg/L	13.9%
10 to 25 pg/L	2.2%
25 to 50 pg/L	1.1%
> 50 pg/L	0.2%
No answer	30.0%
Arsenic Treatment Installed	63.4%
By me / my family	30.7%
By previous owner or landlord	32.7%
Not Treating but Avoid Water	8.2%

[†]Multiple answers accepted

Table 3:

Arsenic treatment (n=308)

Variable	Frequency
Came with Home	46.8%
Median Cost	$3000
Median Years Since Installation	7
Mention Service Agreement	27%
Treated Water Has Ever Been Tested	73.7%
Within the past year	30.8%
Within 5 years	51.9%
Maintenance is Performed	
As recommended	57.3%
Less often	16.9%
Much less often	6.0%
Rarely or never	17.9%
Don’t know	2.0%

Table 4:

Odds ratios (OR) and 95% confidence intervals of logistic regression models predicting mitigation (either treating or avoiding water) (n=486).

	Univariate	Model 1	Model 2	Model 3 <8 years	Model 3 ≥8 years
Explanatory Variables					
Recall Test	2.24** (1.33–3.79)	0.74 (0.27–1.98)			
Report Correct Level	1.92* (1.08–3.39)	0.76 (0.37–1.57)			
Identify Arsenic Problem	17 5*** (10.4–29.5)	8 40*** (4.42–15.97)		1.86 (0.53–6.48)	5.54*** (2.22–13.8)
Difficulty Understanding Report	0.98 (0.78–1.23)				
Discussed Arsenic with Somebody	12 43*** (7.67–20.2)	3.96*** (2.19–7.14)		3.83* (1.12–13.12)	1.56 (0.65–3.73)
Arsenic Value	1.04** (1.01–1.06)			0.98 (0.95–1.02)	1.03 (0.98–1.08)
Behavioral Factors					
Perceived Susceptibility	2 54*** (2.10–3.08)		2.16*** (1.67–2.79)	1.86* (1.16–2.99)	1 77** (1.23–2.54)
Perceived Severity	1 97*** (1.63–2.38)		1.31 (0.93–1.84)		
Perceived Benefits	2 11*** (1.70–2.61)		1.03 (0.75–1.43)		
Perceived Barriers	0.82* (0.70–0.96)		0.73** (0.58–0.93)	1.06 (0.65–1.74)	0.65** (0.48–0.89)
Self-Efficacy	1.50*** (1.28–1.77)		1.45** (1.15–1.82)	1.48 (0.94–2.33)	1.36* (1.02–1.81)
Commitment	1 92*** (1.56–2.35)		1.20 (1.20–1.61)		
Cue to Action	1.62*** (1.35–1.95)		1.38** (1.11–1.71)	1.52 (0.97–2.37)	1.21 (0.91–1.61)
Sociodemographic					
Bachelor's degree	1.57 (0.99–1.52)				
Years in Home	0.95** (0.92–0.98)				
AUC		.8428	.8642	.8936	.8988

Model 3 is stratified by time since home purchase (< 8 years and ≥ 8 years). AUC = area under ROC curve.

* p<.05,

** p<.01,

*** p<.001

Table 5:

Odds ratios and 95% confidence intervals of logistic regression models predicting treatment use (n=486).

	Univariate	Model 1	Model 2	Model 3 <8 years (n=193)	Model 3 ≥8 years (n=277)
Explanatory Variables					
Recall Test	3 73***	1.17			
(2.19–6.36)	(0.42–3.25)				
Report Correct Level	2.12**(1.25–3.59)	0.91(0.45–1.83)			
Identify Arsenic	22.58***	7 38***		3.88*	8 41***
Problem	(13.9–36.7)	(4.02–13.55)		(1.06–14.17)	(2.78–25.5)
Difficulty	0.80*	0.73*		1.00	0.86
Understanding Report	(0.65–0.98)	(0.56–0.95)		(0.54–1.83)	(0.55–1.36)
Discussed Arsenic with	19 1***	5.76***		3.93*	1.25
Somebody	(11.9–30.6)	(3.24–10.2)		(1.06–14.5)	(0.43–3.62)
Arsenic Value	1.03**(1.01–1.06)			1.00 (0.96–1.05)	1.07*(1.01–1.14)
Behavioral Factors					
Perceived Susceptibility	2 83***(2.32–3.46)		3.10***(2.31–4.16)	1.75*(1.04–2.95)	2.03**(1.26–3.25)
Perceived Severity	1.80***(1.52–2.14)		1.00(0.71–1.41)		
Perceived Benefits	1 91***(1.56–2.34)		0.80(0.57–1.13)		
Perceived Barriers	0 74***(0.64–0.86)		0.65***(0.51–0.83)	0.78 (0.43–1.41)	0.60**(0.41–0.87)
Self-Efficacy	1.80***(1.52–2.14)		1.48**(1.17–1.86)	1.21(0.74–1.98)	1.47*(1.02–2.10)
Commitment	2 44***(1.97–3.03)		1.72**(1.25–2.38)	1.87 (1.00–3.49)	1 94**(1.24–3.06)
Cue to Action	1 41***(1.23–1.63)		1.17(0.97–1.42)		
Sociodemographic					
Bachelor's Degree	1.89**(1.23–2.92)			11.51**(2.90–45.74)	1.56(0.57–4.26)
Years in Home	0.95**(0.92–0.98)				
AUC		.8662	.8899	.9109	.9346

Model 3 is stratified by time since home purchase (< 8 years and ≥ 8 years)

*p<.05

**p<.01

***p<.001

Table 6:

Odds ratios and 95% confidence intervals for logistic regression models predicting recent monitoring (have tested treated water in last year), among treating (n=308)

	Univariate	Model 1	Model 2	Model 3
Explanatory Variables				
System age	0.92 *(0.86–0.99)	0.92 *(0.86–0.99)		0.94(0.87–1.01)
Seller installed	0.64(0.39–1.04)			
Difficulty Understanding Report	0.71 **(0.55–0.91)	0.70 *(0.55–0.93)		0.74(0.55–1.00)
Discussed Arsenic with Somebody	1.75(0.85–3.57)			
Service Agreement	2.42 **(1.43–4.11)	2.33 **(1.28–4.22)		1.86 *(1.00–3.45)
Arsenic Value	1.01(0.99–1.02)			
Behavioral Factors				
Perceived Severity	1.36 **(1.09–1.68)		1.24(0.97–1.58)	1.35 *(1.05–1.74)
Perceived Benefits	1.32(0.99–1.75)			
Perceived Barriers	0.82 *(0.68–0.98)		0.89(0.73–1.08)	
Self-Efficacy	1.54 **(1.17–2.02)		1.36 *(1.00–1.85)	1.32(0.96–1.80)
Commitment	1 74 **(1.22–2.47)		1.22(0.80–1.86)	
AUC		.6617	.6610	.6865

* p<.05

** p<.01

*** p<.001

Table 7:

Odds ratios and 95% confidence intervals for logistic regression models predicting maintenance as recommended, among treating (n=308)

	Univariate	Model 1	Model 2	Model 3
Explanatory Variables				
System Age	0.96(0.90–1.02)			
Seller Installed	0.55 *(0.35–0.86)	0.54 *(0.33–0.89)		0.60(0.36–1.02)
Difficulty Understanding Report	0.73 **(0.58–0.91)	0.71 **(0.55–0.91)		0.79(0.60–1.03)
Discussed Arsenic with Somebody	1.84 *(1.00–3.38)	1.54(0.78–3.04)		
Service Agreement	3 24 ***(1.84–5.72)	4 08 ***(2.17–7.66)		3.50 ***(1.83–6.70)
Arsenic Value	1.03 *(1.00–1.05)			1.02(0.99–1.04)
Behavioral Factors				
Perceived Susceptibility	1.16(0.94–1.41)			
Perceived Severity	1.39 **(1.15–1.68)		1.23(0.95–1.59)	
Perceived Benefits	1.40 *(1.09–1.81)		0.89(0.63–1.27)	
Perceived Barriers	0.80 *(0.68–0.95)		0.90(0.75–1.09)	
Self-Efficacy	1.68 ***(1.33–2.12)		1.41 *(1.08–1.84)	1.18(0.89–1.56)
Commitment	2 17 ***(1.60–2.95)		1.64 *(1.11–2.43)	1.64 **(1.15–2.33)
AUC		.7126	.7093	.7536

* p<.05

** p<.01

*** p<.001