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Improve Private Well Testing Outreach Efficiency by Targeting Households Based on Proximity to a High Arsenic Well

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Abstract

Research into precautionary action suggests outreach with personally-relevant risk information may help overcome optimistic biases, which have been shown to impede voluntary testing for arsenic by at-risk private well households. Since 2002, New Jersey's Private Well Testing Act (PWTA) has required testing for arsenic during real estate transactions. The PWTA database of over 35,000 geocoded well arsenic tests offers a unique opportunity to evaluate the efficacy of targeted outreach to neighbors living in proximity to a known high arsenic well with variable risk messaging to motivate testing. In this study, residents of properties (n=1743) located within 500 feet and between 500 and 1000 feet of a known high arsenic well (> 5 μg/L, New Jersey's drinking water arsenic standard) were mailed a notice of the high arsenic result in their neighborhood and offered a free water test. Overall 274 households (16%) requested a test kit and 230 (13%) ultimately submitted a water sample; with significantly higher participation rates among those told their neighborhood well had an arsenic concentration "*over 5 times higher*" than the standard, compared to those told the concentration was "*above*." Overall, 25% of wells tested (n=230), and 47% (n=66) of non-treated wells located within 500 feet of a well with > 25 μg/L arsenic, exceeded the standard for arsenic. Both the arsenic concentration and distance to the neighboring well were significant predictors of exceedance. Given the high proportion of previously untested wells (70%) and their owners' lack of awareness of arsenic in their area (80%), this targeting approach succeeded not only in identifying a much higher proportion of at risk wells than blanket

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Credit Author Statement:

Flanagan: study design, data collection and analysis, writing. Procopio: study design, PWTA data analysis, and review. Spayd and Gleason: study design and review. Zheng: study design, supervision, review & editing.

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testing by town or county, but also in motivating testing among households unreached by prior awareness-raising activities. In conclusion, geographically and personally-relevant risk targeted messaging and outreach are both efficient and effective.

Keywords

private well; arsenic; spatial heterogeneity; drinking water testing; public health; outreach

1. Introduction

Inorganic arsenic is naturally occurring in groundwater throughout the U.S. and is a public health concern when groundwater is a source for drinking. More concerning is that private well water, relied on by 15% of the U.S. population [1], is unregulated under the 1974 Safe Drinking Water Act and there is no federal requirement that private water be monitored or meet drinking water standards for quality. Recent modeling predicts that 2.1 million people (95% CI: 1.5 – 2.9 million) living in the conterminous United States are currently drinking from wells that exceed the federal Maximum Contaminant Level (MCL) of 10 μg/L for arsenic [2].

Chronic arsenic exposure through drinking water is associated with increased risks of cancer, cardiovascular disease, non-neoplastic respiratory changes, and neuropathy [3, 4]. Evidence continues to grow for the critical exposure period *in utero* and early life, where arsenic at even relatively low concentrations impairs intellectual development and increases the risk of adverse health effects later in life [5–8]. In 2004, New Jersey became the first state to adopt an arsenic MCL lower than the federal standard, and at 5 μg/L remains the most protective in the nation [9]. New Hampshire is the only other state to have adopted an MCL of 5 μg/L, expected to go into effect in 2021. Nevertheless, enforceable MCLs apply only to publicly supplied water which is protected under strict regulatory oversight. Consistent with other carcinogens, EPA's MCL-Goal for arsenic is 0 μg/L, meaning there is no level in drinking water which could be considered safe.

Since private well water is considered a private responsibility, many well owners and users remain unaware of the risks posed by naturally occurring groundwater contaminants, particularly arsenic. Sensory and visibility factors are consistently the strongest prompt for private well users to investigate the quality or safety of their drinking water [10, 11]; prompts which are absent for arsenic which cannot be seen, smelled, or tasted in water.

Well owners must be aware, willing, and capable of acting on their own to have their water tested and to take all actions necessary to ensure their water is of safe quality, bearing the costs along the way. At present the greatest barrier to arsenic exposure reduction remains a lack of testing; after universal screening is achieved and all unsafe wells are identified, the challenge will shift to mitigation. However, even in areas known to have frequent arsenic contamination of well water, surveys reveal that a majority of households have still never tested for arsenic [11–13]. The threat of arsenic to drinking water continues to fly under the radar; well owners tend to underestimate environmental hazards such as arsenic when the problem is naturally occurring, not industrial, and if remediation is their own responsibility and not a government or corporate one [11, 14]. While testing regulations like New Jersey's Private Well Testing Act (PWTA), which mandates water quality tests during real estate transactions, are policy achievements ensuring that eventually every well will be tested [15, 16], in practice it will take decades to reach universal testing due to the rate of housing turnover [12]. Such policy advances don't negate the need for active public outreach; however, they do provide new opportunities to improve the effectiveness of targeting and communicating in the form of much needed water quality data.

Arsenic testing only detects a health risk and does not immediately reduce it, thus the factors influencing testing decisions can be more complicated than with other health behaviors. In particular, individual risk perception for arsenic is often optimistically biased such that risks to self are estimated as significantly lower than comparison group estimates; for example, people believe that wells in their town are more at risk of arsenic contamination than their own well [11, 14, 17, 18]. This may explain why even residents informed of local risks may still not feel enough personal risk to warrant testing action. Personal experience with the "good" quality of one's drinking water can also serve to reinforce cognitive biases [19]. Despite these biases, higher threat perceptions are correlated with increased testing behavior [20]. Private well owners reported they would test their water after hearing a neighbor's well is contaminated at nearly twice the rate as hearing that wells in their town are contaminated [11, 12], indicating that more personalized risk messaging, such as highlighting danger in neighbor's wells, may be necessary to overcome cognitive biases.

Research into precautionary action suggests that in the absence of personal experience with hazards, programs emphasizing concrete, personalized information about likelihood, severity, and precautions, and programs attacking unrealistic optimism will be more successful than traditional attempts to disseminate general hazard information to the public [21]. Interventions that can incorporate "vivid" and "self-relevant" information may better influence personal-level judgements of risk [22]. Periodic community testing campaigns are rarely designed to overcome testing barriers or confront cognitive biases, and individual outreach across a population may be considered cost-prohibitive. While high degrees of spatial variability mean that neighboring wells are not consistently safe or unsafe, and therefore all wells must be tested, proximity to another well with elevated arsenic does suggest a higher probability of arsenic exceeding the MCL due to the shared underlying geology of an area [23]. To the best of our knowledge, the efficacy of personalized risk communication highlighting the arsenic hazard based on a real test result in a neighbor's well has not been previously assessed.

The aim of this study is to describe and evaluate a pilot intervention to notify and offer arsenic testing to such high-risk neighbors of private wells with known arsenic exceedance, assessing its impact in terms of participation and the effect of this targeting on identifying more unsafe wells. Here, a growing database of geocoded well test results, New Jersey's PWTA records, is leveraged to evaluate the efficacy of targeting neighbors within 500 feet and between 500 to 1000 feet of high arsenic wells.

2. Methods

2.1 Study area and background

Although private well testing is a federally unregulated individual responsibility, there are local exceptions, such as New Jersey's Private Well Testing Act (PWTA), which since September 2002 has required private wells be tested for specific contaminants during real estate transactions, including for arsenic in the 12 northern counties of the state. PWTA test results must be submitted to the New Jersey Department of Environmental Protection (NJDEP) and maintained in a database for the purposes of studying groundwater in the state. Results from a well that exceed any of the required parameters are also shared with the relevant county or local health department jurisdiction who may contact any neighbors living within at least 200 feet of the well to perform outreach; however, these notices are at the sole discretion of the local authority. Anecdotal evidence suggests that these notifications are not always made for naturally occurring contaminants like arsenic. Reasons include no provision for additional funding or resources for local authorities to take on this work, and concerns over maintaining confidentiality when the neighboring property in question could be easily identified by the recent "for sale" sign on the front lawn.

Due to the pace of housing turnover, only about 25% of private wells in New Jersey have been tested through the PWTA, and surveys suggest that the majority of wells not required to be tested by the PWTA as of yet have not been independently tested for arsenic [12]. Yet since 2002 the PWTA database has amassed arsenic test results from over 35,000 private wells, including over 4,000 with arsenic concentrations above the New Jersey MCL of 5 μg/L, yielding valuable spatial insight into the most at-risk areas (Figure 1). This data presents an opportunity for targeted outreach to the neighbors of contaminated wells identified over the past 14 years.

2.3 Targeted Mailing and Variable Risk Messaging

Although exact locations of wells on neighboring properties are unknown, residential parcels located within 1000 feet of a well exceeding the NJ MCL were identified following the methods described in Supplementary Information (SI). A total of 2,000 addresses were selected from a potential list of over 60,000, stratified by arsenic level of the neighboring PWTA well (>25 μg/L, 10–25 μg/L, and 5–10 μg/L) and distance to the neighboring well (< 500 feet, 500–1000 feet). Selected addresses represented 99 municipalities, in 10 counties of New Jersey. All were mailed a letter in November or December 2016 from Columbia University Lamont-Doherty Earth Observatory notifying the current residents that a neighboring well exceeds the state's drinking water standard for arsenic and offering a free arsenic test of their water through Columbia's laboratory (see SI).

Letters informed individuals that the test was voluntary, and the results would be kept secure and confidential. The free test was meant to remove any financial barriers to participation [24, 25]. Included with the letters was a postage-paid return postcard that could be mailed by the resident to request or decline the free arsenic test. Residents also had the option to request the test by email. Those who requested a test kit were then mailed bottles and instructions for sampling their tap water with a pre-paid return package. Included with the sample bottles was a brief survey on testing history, treatment use, and perceptions of objective and comparative arsenic risk likelihood rated on a Likert scale. Participants were mailed or emailed full test results for their samples; those whose water exceeded the drinking water standard for arsenic (or any other parameter tested for) were provided with additional guidance on next steps.

Selected addresses were mailed one of three (3) risk versions of the letter based on the arsenic level of their neighboring PWTA well: low risk message ("arsenic at levels above…" if the neighboring well has an arsenic concentration between 5 and 10 µg/L), medium risk message ("arsenic at levels *several times higher than*" if the neighboring well had an arsenic concentration of 10 to 25µg/L), and high risk message ("arsenic at levels *over 5 times higher than*" if the neighboring well had an arsenic concentration greater than 25 µg/L). Each letter also included one of three versions of a color-coded visual scale graphic, adapted from a study by Severtson and Henriques [26] which found that using this plain scaled image to express drinking water test results conveyed a stronger risk message to participants than a typical alphanumeric lab report or a more detailed graded image, and prompted meaningful risk reduction intentions among participants with optimistically biased safety threshold beliefs. The adapted images indicated the "range of arsenic level" in the neighborhood well, which varied based on the three arsenic level categories (Figure 2).

2.4 Water sample analysis

Water samples collected from participants were acidified to 1% HNO_3 (Optima Grade) before analysis by high resolution inductively coupled plasma-mass spectrometry (ICP-MS) by Columbia University following previously established protocol [27]. Repeated analyses of the standard solution NIST 1643e (n=6) with 60.5 µg/L and a quality control sample (n=6) with 9.5 µg/L of arsenic revealed an accuracy within 2.7% and a precision within 1.8%. The detection limit for arsenic was < 0.02 µg/L.

2.5 Statistical analysis

Descriptive analysis, correlation, and regression analyses employed STATA IC v14. All statistical tests were two-tailed and p-values < 0.05 were considered significant. Significant differences in participation by risk message were identified by chi-square tests and pairwise 2-proportion z-tests. Logistic and linear regression were used to predict arsenic exceedance and concentration, respectively, from neighbor's arsenic level, neighbor's distance, and town exceedance rate based on PWTA testing records. Two samples suspected of being from a public water supply and 14 reportedly being treated for arsenic were excluded from those regression analyses,

3. Results

3.1 Response to intervention

Of the 2000 addresses selected, 181 letters were returned as undeliverable (Table 1). Several (n=35) postcard responses indicated there was not a private well at that address. An additional 50 non-responding addresses were excluded post-mailing as potentially non-residential after review of property values in the NJ state tax database found that they had a total property value of less than $50,000 with an "improvement value" above land value of zero, suggesting there are no buildings on the property. Only 5 return postcards were received declining a test because they had already tested for arsenic, rather than that there is no private well on the property.

A total of 274 letter recipients, or 16% of the households notified (total letters mailed excluding undeliverable, no well and non-residential), requested a test kit. Most requests came by postcard, with only 13% by email. The median time until kit request was 18 days (range 3 to 239), with 23% of requests received after the initial deadline. Seven additional test kits were mailed to addresses not selected in the target sample at the request of participants, 3 for family members nearby and 4 for neighbors, and several additional requests were turned down. Six letter recipients who returned the postcard more than 4 months after the deadline were not mailed a test kit. Two kits mailed out were returned as undeliverable despite a kit requested from that address. Overall, among those notified of the test offer, 13% (224) submitted water samples and an additional 6 samples were received from the extra kits mailed, for a total of 230 well water samples collected (Table 1). However, at least two returned samples are believed to be public water and not private well water, based on the information provided by the recipients with their sample form.

3.2 Characteristics of participants

Most participants (97%) who sent samples live in a home that they or another family member own. Only 7 samples were sent from rental properties. The participants are highly educated (66% with a bachelor's degree); unfortunately, there is no education information on the non-responders for comparison. Although no household income information is available for any selected addresses; property values from state tax records can be used to compare those who requested a test kit to non-responders as a proxy measure for socioeconomic status (Table 2). The median home value among those who requested a test kit is significantly higher than the median among selected addresses with no response ($p<.05$) and a Mann-Whitney test confirms the distributions of property value are significantly different between groups ($p<.05$); however, property value is not a significant predictor of test kit requests in logistic regression.

Only 30% of participants report having tested their well water for arsenic before, although another 25% do not know if it has been tested (Table 3). Among those who have tested for arsenic previously, the median for time of last test was 4 years ago, with a range between 1 and 25 years. One third of wells previously tested for arsenic reportedly exceeded the NJ state standard of 5 μg/L, and 21% were reportedly being treated for arsenic. Testing history is significantly different by education level; participants with a bachelor's degree have 2.6 times greater odds (95% CI 1.3–5.2) of having tested for arsenic previously compared to those with lesser education. Among those who have not tested for arsenic before, the most common reason given was not knowing arsenic was a problem in their area (80%), and second that they kept forgetting or hadn't gotten around to testing (11%). Nearly half of participants do not treat their water at all, and water softeners are the most common treatment used (34%). Only 6% of overall participants report they use arsenic removal treatment. There was no arsenic treatment use reported among those who had not tested their well water for arsenic before.

Of the 7 study participants living in a rental home, none reported having ever seen a report on their water quality and none were aware of the level of arsenic in their water, despite a PWTA provision that private wells serving rental properties be tested every five years and that the most recent results be provided to tenants upon signing a lease. One of these water samples ended up having the highest concentration of arsenic in this study (66 μg/L).

3.3 Effect of targeting by neighbor's arsenic level and distance to well

Overall, 26% of the tested wells that do not currently have arsenic treatment units (n=214) were found to exceed the arsenic standard of 5 μg/L (Table 4). Arsenic was detectable (>0.02 μg/L) in 96% of wells. The median arsenic concentration of wells sampled was 1.9 μg/L, mean was 4.7 μg/L, and the maximum arsenic concentration measured was 66 μg/L. Arsenic exceedance among wells reported as never tested before (n=160) was 25%. Full water quality results for arsenic and other parameters are reported in Table S1.

Among tested wells without an As treatment unit, sampled arsenic concentrations are significantly predicted by neighbor's concentration (β=0.08, p<.001) and neighbor's close distance (β=4.75, p<.001) in a linear regression model. Neighbor's arsenic level is not a significant predictor of exceedance when limiting to wells on properties more than 500 feet away (Figure 3). A high (>25 μg/L) arsenic well significantly predicts (p<.05) odds of an arsenic exceedance (>5 μg/L) compared to a neighbor with arsenic between 5 and 10 μg/L (OR=2.30), even more strongly when adjusting for neighbor's distance (OR=3.19) (Table 5, Model 1). Neighbor's arsenic concentration as a continuous variable is only a marginally significant predictor (p<.06) of arsenic exceedance, regardless of whether distance is controlled for. However, the strongest predictor of exceedance is being within 500 feet of the neighboring arsenic well; when adjusting for neighbor's arsenic category, a well within 500 feet has 7.4 times the odds of exceeding the arsenic standard than one between 500 and 1000 feet away (p<.001).

Town arsenic rate, the percentage of PWTA tested wells in each municipality which exceed the arsenic standard, is a significant predictor of both arsenic concentration and arsenic exceedance among sampled wells not treating for arsenic. Each 5% increase in town exceedance rate is associated with a 0.7 μg/L increase in arsenic concentration and 26% greater odds of the sample exceeding the standard (Table 5). Town rate remains a significant predictor of concentration and exceedance after adjusting for neighbor's arsenic value and distance, which also remain significant predictors in the adjusted model (Table 5, Model 2).

3.4 Influence of risk messaging

Receipt of the high-risk letter was statistically significant (Table 6) for requesting a test kit compared to receiving the lower risk letter (17.4% vs. 12.8%, p<.05), and compared to the medium and low risk letter groups combined (17.4% vs. 13.6%, p<.05). Although there was no difference in the rate of returning water samples among those who requested test kits, overall participation (samples sent by those notified) was significantly higher among those receiving a high arsenic risk letter compared to each of the alternative letters and both combined (14.9% vs. 10.5%, $p<.01$).

3.5 Risk perceptions

Among private well users who had not tested their water for arsenic before, receiving a high risk message letter is significantly associated ($p<.05$) with perceived likelihood of having arsenic above the NJ standard, compared to those receiving the low risk message letter (Figure 5). The high risk message letter remains a significant predictor after controlling for education. However, there is no difference between risk message categories in the proportion of recipients who believe they are actually likely to have arsenic above the standard (~9%). While few recipients of high risk message letters believed that their own well is likely to exceed the arsenic standard, the notice does appear to have reduced their resistance to that possibility, with more reporting that it is "about as likely as not" rather than "unlikely" or "very unlikely," compared to those receiving other versions of the letter (Figure 5).

When asked how they think their arsenic level compares to other wells in their neighborhood, the differences by risk message are not significant. One third said they had no idea how their level compares. Among those who gave a response (Figure 6), 94% believe their arsenic level is either about average or lower than average.

4. Discussion

4.1 Increased Testing

Although the overall participation was lower than expected given that 75% of respondents to a recent survey in this area indicated that learning their neighbor had contaminated well water would prompt them to test their own [12], this outreach strategy did succeed in generating 228 tests of private wells, 70% previously untested, through a single mailed letter with a free testing offer. This untested rate is consistent with a recent survey in northern NJ where only 35% of private well owners who purchased their home prior to the PWTA report their water has been tested for arsenic [12]. Considering most untested participants reported their reason for not previously testing was because they weren't aware that arsenic was a problem in their area, this intervention succeeded in motivating households unreached by any community testing or awareness activities in the 14 years since the PWTA first confirmed widespread arsenic contamination in northern New Jersey. At this participation rate, the direct costs including materials, mailing, and shipping expenses came to about $30 per tested well, not including ICP-MS costs and professional time.

Typical testing campaigns, when held, remain small scale, and although published evaluations of these programs are rare, evidence suggests their success is limited as usually only a fraction of at-risk wells in a community will be tested. For example, in New Jersey, the Raritan Headwaters Association (RHA) Community Well Testing (CWT) Program regularly partners with townships to provide convenient annual testing opportunities whereby test kits are picked up and dropped off on set days, typically at the municipal building. Their basic test is for bacteria and nitrates, recommended annually, and is available for $70. Arsenic and other contaminants are available to add on for a fee. According to RHA, typically 2–5% of the private wells in a township are tested during a CWT event, even fewer for arsenic (personal communication). The few published evaluations of other community testing campaigns suggest that more intensive outreach efforts can generate higher participation. For example, a community-based intervention following a mass media campaign increased the arsenic screening rate from 4 to 16% in one municipality of Québec [28]. A 2-year community informational and testing campaign in the small town of Tuftonboro, NH tested 28% of the wells in the town [29]. In Wisconsin a 3-year educational arsenic well test program in 19 towns of an arsenic advisory area was able to motivate about 30% of residents to participate [30]. However, introducing and expanding more intensive outreach efforts may be beyond the means of many local governments and organizations. Complementing general community awareness-raising and testing opportunities with targeted outreach to households of known risk is likely to provide a more effective balance of efforts.

The significantly higher response among those notified that their neighborhood well had arsenic over 5 times higher than the drinking water standard indicates that describing levels in this way as comparatively high may be perceived as a greater risk than simply “exceeding” a standard, thus warranting action. The significant effect of the comparatively high risk phrasing has since been replicated in later mailings, lending further support. Although we have no measure of risk perceptions among participants prior to receiving the letter, the random selection of addresses suggests that the observed significant differences in perceived objective risk likelihood may be attributable to the variation in letter message. Emphasizing and interpreting such comparative risks relative to standards when local information is available may help to overcome testing reluctance. Even so, the strong optimistic bias against having a high arsenic well among those who received notice of their neighbor’s high level and chose to participate in this testing opportunity, suggests major challenges to overcoming this barrier in the general population, especially if testing is not offered for free.

Although there are no income or education measures to compare participants to non-responders, the difference in their median property values is consistent with our prior findings that higher-income households are more likely to participate in testing opportunities, even when the test is free [24]. A recent survey of private well owners in Minnesota suggests that participation in testing programs may also be influenced by the method in which test kits are requested and returned. The investigators found that higher income, higher education, and younger individuals were significantly more likely to prefer ordering a test kit online and returning the sample by mail, whereas lower income, lower education, and older participants preferred to pick up and return test kits at a local location [31]. Here, participants with a bachelor’s degree were also significantly more likely to have tested their well for arsenic before, as has been observed by surveys in New Jersey and Maine [25]. This confirms the need to develop testing outreach strategies that are better targeted to more socially vulnerable populations and to overcoming their specific barriers to testing. Furthermore, efforts to change policy towards requiring private well testing at occasions beyond real estate transaction may be necessary to overcome the socioeconomic patterns observed when testing is primarily voluntary.

4.2 Effectiveness of targeting

Random testing of private wells in the northern half of New Jersey, if possible, would presumably yield a similar exceedance rate to the 8.9% found to exceed the state MCL among the 35,000 arsenic tests required by the PWTA during real estate transactions in that area. With an identified exceedance rate of 25%, the targeting strategy evaluated here is more effective at identifying problem wells than blanket testing requirements; however, the benefit of a regulation such as the PWTA is that eventually every well will be tested over a long enough time horizon. Yet out of 35,000 residential wells tested for arsenic in northern New Jersey since 2002 the PWTA has identified only 175 (0.5%) with arsenic concentrations above 25 μg/L, while 9 of 228 wells (4%) sampled through this intervention had arsenic above that level. Moreover, nearly one of every two wells tested when targeting homes within 500 feet of a high arsenic (>25 μg/L) neighbor were found to exceed the NJ drinking water standard (Figure 4), suggesting a highly efficient targeting strategy.

Of the 10 counties represented in this study, the range of PWTA arsenic tests exceeding the MCL is between 1.3% and 16.3%, with 6 counties above a 2% rate. County-based targeting would understandably focus on the few with the highest rates. Yet close neighbors of a PWTA well with > 25 μg/L arsenic were selected for this intervention from all 10 counties. Although sample selection across the state was not meant to be representative at the county or town level, the results of this study do provide an interesting comparison to the PWTA rates. In Warren County, where only 1.6% of 1,947 PWTA wells exceeded the arsenic MCL, 5 of 12 wells sampled in this study (42%) exceed 5 μg/L. In Vernon Township, 1.7% of 542 wells tested under the PWTA exceeded the MCL, whereas 4 of 9 wells sampled (44%) here exceed the standard. With such a low town rate from PWTA sampling, this township would not likely be a priority for testing outreach, and arsenic would not likely be a priority within the local health department. Yet targeting outreach to the neighbors of known high arsenic wells could more efficiently identify the households most likely to have a problem in low exceedance areas.

Even in towns with high arsenic exceedance rates, such as Raritan Township where 24.6% of PWTA tests have exceeded the MCL, initially targeting outreach to neighbors of known problem wells can identify more affected households (41% of n=22 wells tested here) and help build testing norms and awareness in the larger community. Knowing someone with an arsenic problem is a significant predictor of testing one's own well for arsenic [11, 12]. Identifying more wells with problems can only help to drive testing rates in a community as more people learn of their own risks through interpersonal channels and social networks. The finding that town exceedance rate remains a significant predictor of a neighboring well's exceedance, even when adjusting for distance and arsenic concentration, suggests that the neighbor-targeting strategy could be employed to greatest effect in areas of frequent arsenic occurrence.

NJDEP has publicly identified these local variations in arsenic-risk, while protecting the confidentiality of individual wells, by mapping arsenic exceedance rates from PWTA testing within 2×2 mile areas (https://arcg.is/18XzGb). This has highlighted local hotspots that could be targeted in future outreach, although even at such a scale the problem can be obscured. While one out of 20 PWTA wells tested in a hypothetical 2 square miles area may exceed the MCL (5% rate), that well may be on a block of 10 homes that all have high arsenic but haven't been tested yet; it is important that the remaining 9 households know to test their water too. Indeed, several high arsenic wells identified in this study are in squares where less than 10% of tested wells exceed the MCL (Figure 1). This study found that distance is a significant predictor of arsenic exceedance, even comparing wells within 500 feet to those within 1000 feet; two miles away may be less meaningful. Nearly half (47%) of wells sampled in this study that were located within 500 feet of a high (>25 μg/L) arsenic well were found to exceed the MCL; this is a high priority group that should be informed of their risks as soon as possible. Yet this study found that most participants were not even aware that arsenic was a problem in their area. Targeting neighbors is a strategy that can be done easily and effectively and can complement more general outreach targeted to high risk towns and counties, as well as more specific outreach targeting demographic groups based on biological vulnerability [32].

4.3 Limitations

The low response rate is disappointing considering this was a free test offer targeted to at-risk households; but not surprising given the challenges in motivating people to take protective action around their well water [33]. Unfortunately, the random selection of addresses across the state precludes comparison between participants and non-responders on measures beyond property value. There are several factors that could have contributed to the present low response. First, an unknown portion of non-responding households may not have a private well, since addresses were selected by location only. Second, addresses were selected from property tax records; the number of letters returned as undeliverable shows that those addresses are not always accurate as mailing addresses; many properties could be vacant and more letters undelivered. Third, the timing of the mailings and sample collection, over the Thanksgiving and Christmas/New Year holidays, may have reduced attention paid to the letters and to returning samples. A different time of year, additional follow-up reminders, and longer response windows may have corrected for this.

Lastly, variations in the messages, images, and messenger may have a significant effect on response rate; however, exploring further combinations of these was beyond the scope of this pilot intervention. Replicating this intervention strategy with local health departments as the messenger may have a positive effect on response. New Jersey private well owners rank their local government office as their primary source for information on maintaining the safety and quality of their well water, above state-wide agencies and the private sector [12]. We have since implemented a similar intervention where the Warren County health department sent out notices and test kits could either be requested through an online form or picked up in person; 38% of households requested a kit and over 90% submitted their water sample. Interventions relying on more direct and interpersonal means of contact beyond direct mailing, may also generate greater participation.

5. Conclusions

Despite New Jersey's advantages over other states afforded by the PWTA [16, 34], most private well owners still must act independently to identify risks from their drinking water.

Of the majority of wells not yet required to be tested under the PWTA law, only about a third may have tested for arsenic on their own [12]. While there may be a variety of barriers to testing faced by private well owners, this study highlights an obvious lack of awareness about the widespread occurrence of arsenic in the region; past efforts to promote the need for testing have been insufficient. The study also finds that messages of comparatively high arsenic, relative to standards, can be more compelling than messages of generally high risk. Most importantly, this study has demonstrated that targeted outreach based on localized geographic risk can be effective at uncovering a much higher proportion of contaminated wells than blanket testing or mass media communication across a wider area, which can dilute the personal relevance of messaging. The PWTA has produced a wealth of data that can be used to target efforts toward those most likely to be affected. Many more contaminated wells can be discovered much faster if residents are given notification of their risks, support, and opportunities to test their water when a nearby well exceeds a health-based drinking water standard.

Supplementary Material

Refer to Web version on PubMed Central for supplementary material.

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Highlights:

1. Testing records were leveraged to identify neighbors of high arsenic wells
2. Neighbors notified of proximity to high arsenic wells and offered free water tests
3. Messages conveying higher relative risk motivated more households to test
4. Targeting neighboring wells more than doubled the efficiency of untargeted testing
5. > 60% of wells within 500 feet of a well with > 25 μg/L arsenic exceed the NJ MCL

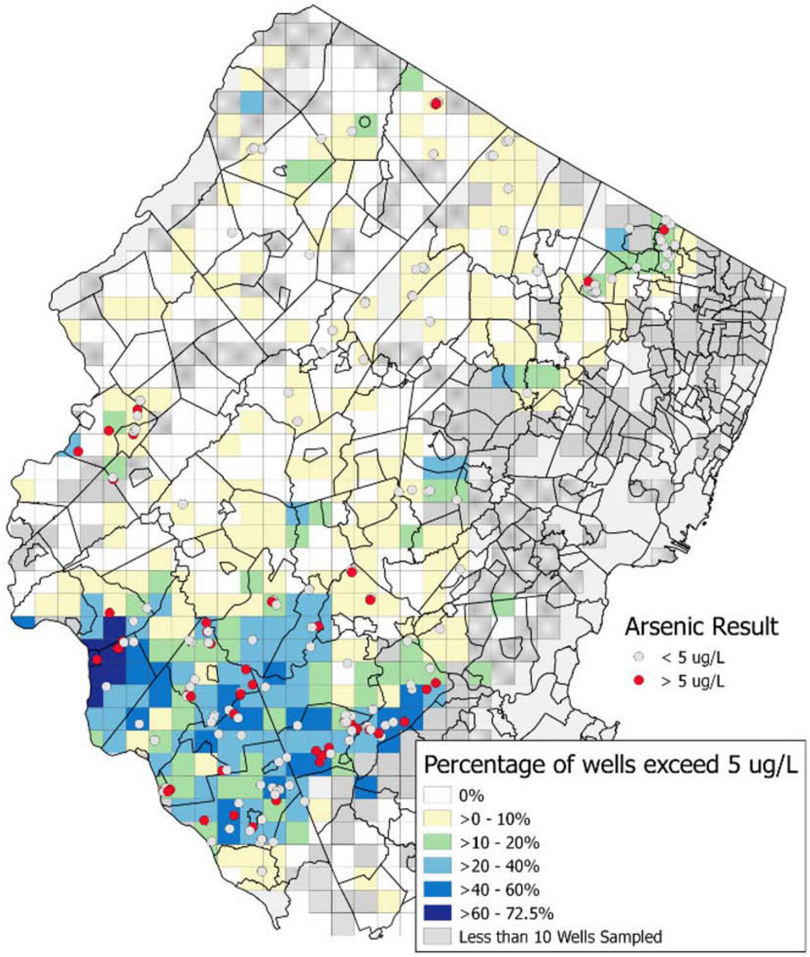

Figure 1:
Location and arsenic level of wells sampled in this study. Local rates of arsenic exceedance are based on over 35,000 PWTA tests (Source: NJDEP)

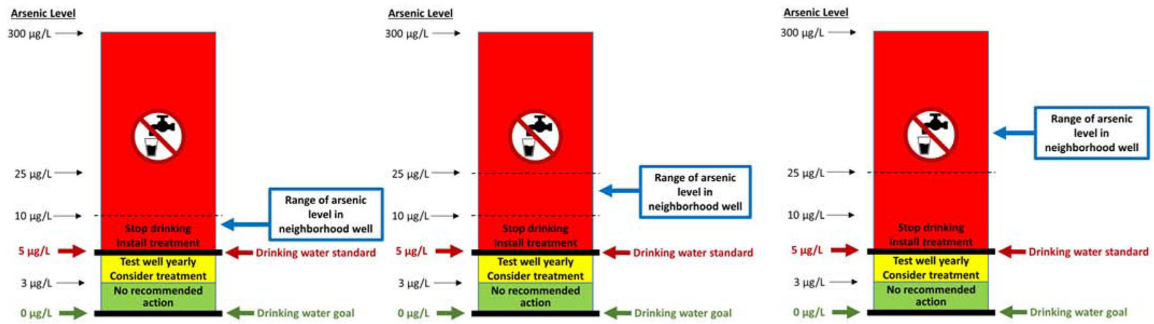

Figure 2:

Three variations in risk graphic included in notice letters

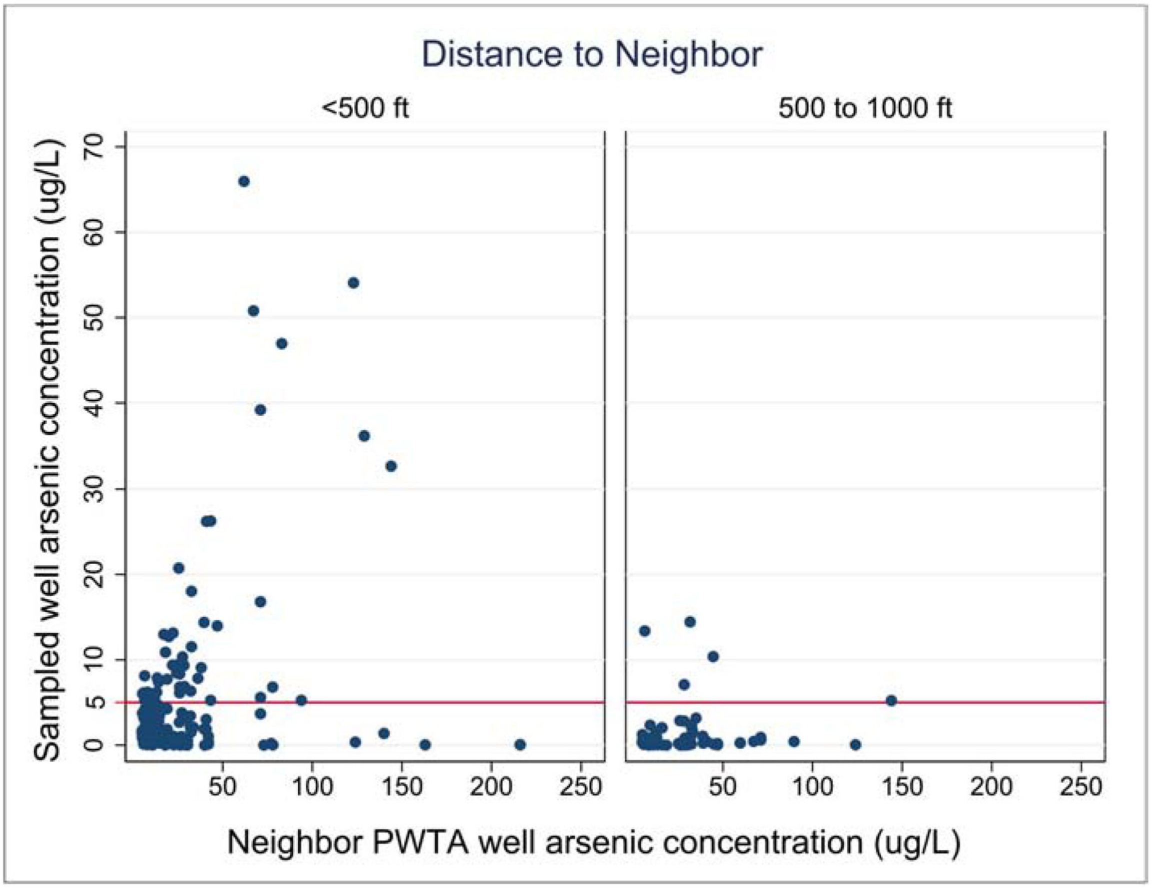

Figure 3:

Scatterplot of sampled arsenic concentration vs. neighbor's arsenic concentration for two distance categories, within 500 feet (n=151) and between 500 to 1000 feet (n=60), excluding those reporting arsenic treatment. The red line indicates the NJ arsenic standard of 5 μg/L.

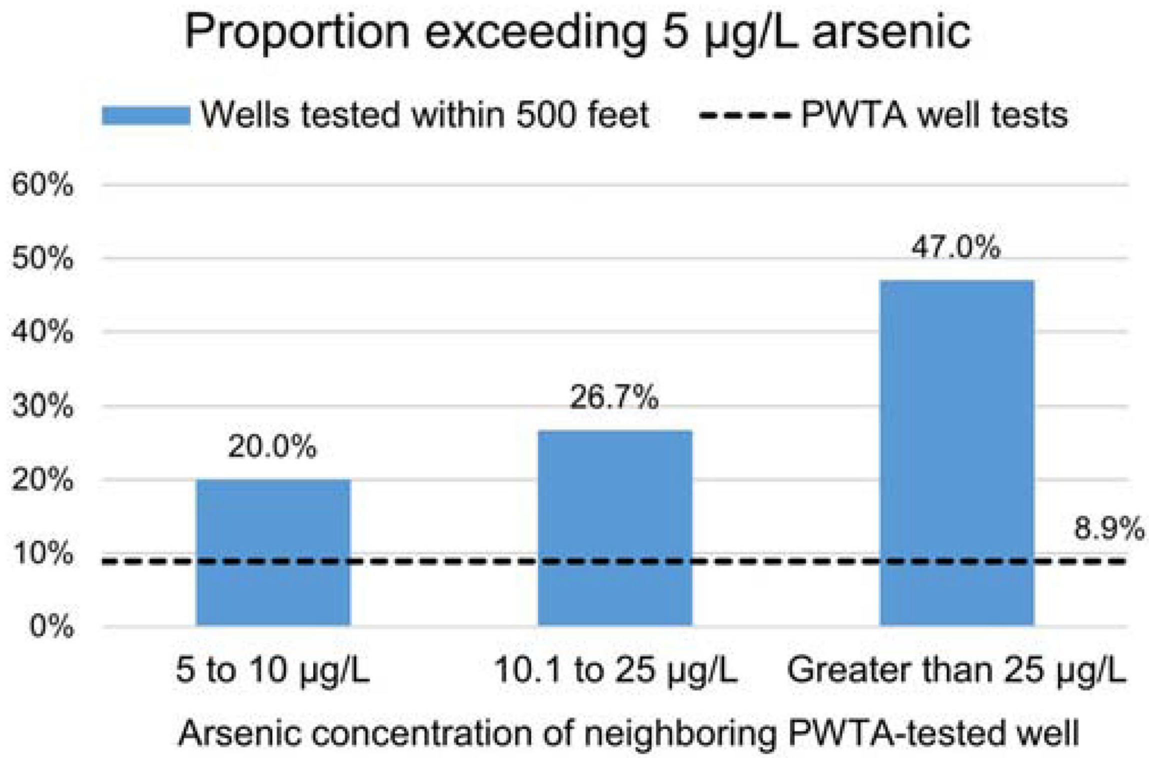

Figure 4.
Proportion of tested wells that exceed the New Jersey drinking water standard by the known arsenic concentration of their neighboring well within 500 feet (n=151), and the proportion of wells tested under the PWTA (n>35,000) found to exceed the arsenic drinking water standard. Wells were randomly selected from the 12 counties in northern New Jersey covered by the PWTA’s arsenic testing requirement.

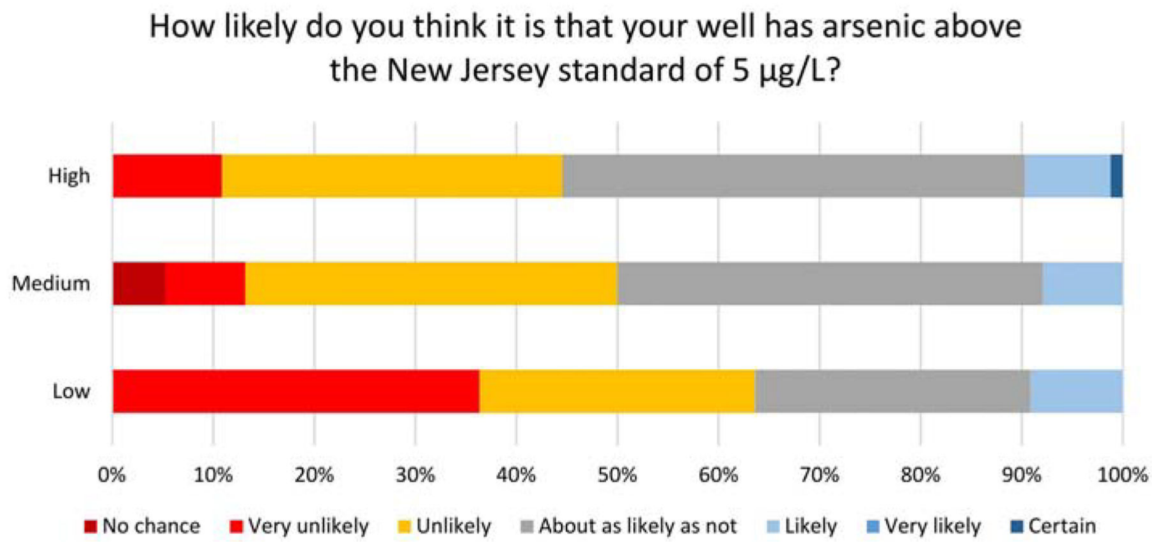

Figure 5:

Perceived risk likelihood among untested only by letter category received, high (n=84), medium (n=38), and low (n=22)

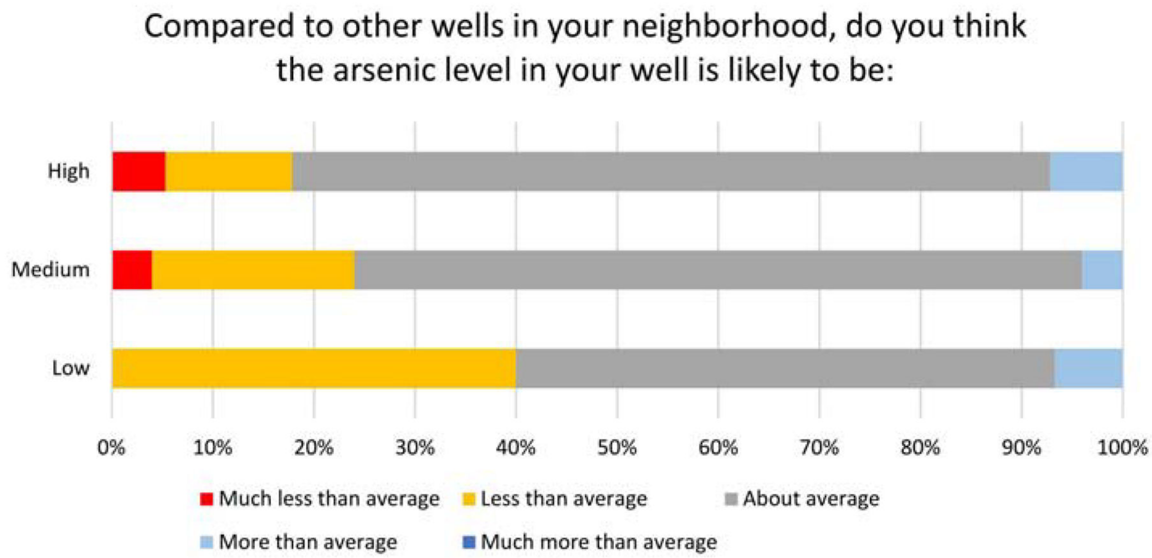

Figure 6:

Perceived comparative risk among untested with an opinion only (n=94) by letter category received, high (n=56), medium (n=25), low (n=15)

Table 1:

Summary of notices mailed and response

	Number
Notices mailed	2,000
By letter message	
> 25 μg/L	1,100
10–25 μg/L	529
5–10 μg/L	371
By neighbor	
> 25 μg/L, < 500 ft	487
> 25 μg/L, 500–1000 ft	400
10–25 μg/L, < 500 ft	323
10–25 μg/L, 500–1000 ft	206
5–10 μg/L, < 500 ft	196
5–10 μg/L, 500–1000 ft	175
Non-deliverable addresses	181
Potential Non-residential	50
No Private Well	35
Kit Requests	274
Samples Received	230

Table 2:

Distribution of property values among notified addresses (n=1,743), by kit request

Property Value	Requested Kit	Notified, No Request
25th Percentile	$240,400	$229,100
Median	$370,200	$343,100
75th Percentile	$519,600	$515,600

Table 3:

Characteristics of testing participants (n=230)

	Percent
Education	
Some high school or less	1%
High School/GED	7%
Some college	25%
Bachelor's degree	28%
Graduate Degree	38%
Arsenic Tested Before?	
Yes	30%
No	45%
Don't know	25%
If tested, did water exceed 5 μg/L? (n=68)	
Yes	32%
No	46%
Don't remember	22%
Why has your well not been tested for arsenic before? (n=162)	
I had never heard of arsenic before	7%
I didn't know arsenic was a problem in my area	80%
The health risks from arsenic did not seem serious	1%
Arranging a test was too difficult or inconvenient	1%
Testing is too expensive	5%
Kept forgetting/Never got around to it	11%
Other	17%
Treatment Use	
None	47%
Water Softener	34%
Reverse Osmosis	4%
Neutralizer	4%
Arsenic Removal	6%
Carbon Tanks	3%
Iron Removal	4%
Anion Exchange	1%
Chlorinator	1%
Other [1]	17%

[1] e.g. UV light (9), sediment filter (12), etc.

Table 4:

Summary of arsenic results by distance to neighbor's well

	Within 500 feet	500 to 1000 feet	All wells
Untreated well water samples	151	60	214
Median (μg/L)	3.1	0.4	1.9
Maximum (μg/L)	66.0	14.4	66.0
Above detection (> 0.02 μg/L)	146 (96.7%)	57 (95%)	206 (96.3%)
Exceed MCL (> 5 μg/L)	51 (33.8%)	5 (8.3%)	56 (26.2%)

Table 5:

Unadjusted and adjusted odds ratios (OR) and 95% confidence intervals for sample exceedance of 5 µg/L by neighbor arsenic level, neighbor distance, and town arsenic exceedance rate (n=211)

	Unadjusted ORs	Model 1	Model 2†
Neighbor Arsenic Level (µg/L)			
5 – 10	1.00	1.00	1.00
10.1 – 25	1.33 (0.51–3.50)	1.27 (0.47–3.38)	1.56 (0.56–4.32)
>25	2.30* (1.01–5.25)	3.19** (1.34–7.57)	3.50** (1.42–8.61)
Neighbor Distance (feet)			
< 500	5.61** (2.11–14.88)	7.44*** (2.72–20.37)	6.95*** (2.48–19.51)
500 – 1000	1.00	1.00	1.00
Town Exceedance Rate (5% increase)	1.26*** (1.11–1.42)		1.23** (1.08–1.40)

* p<.05,

** p<.01,

*** p<.001,

† Model 1 adjusted for town exceedance rate

Table 6:

Response by letter risk message

	Low (5–10 μg/L)	Medium (10–25 μg/L)	High (> 25 μg/L)	Overall
Notified †	336	465	942	1,743
Requested Test	43 (13%)	66 (14%)	165 (17%) *	274 (16%)
Sent a Sample	34 (10%)	50 (11%)	140 (15%) **	224 (13%)

† Notified = (Mailed – Non-delivered – No wells – Potential non-residential)

* Significantly different from other groups (p<.05)

** (p<.01)