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Responses of 6500 households to arsenic mitigation in Araihazar, Bangladesh

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Abstract

This study documents the response of 6500 rural households in a 25 km^2 area of Bangladesh to interventions intended to reduce their exposure to arsenic contained in well water. The interventions included public education, posting test results for arsenic on the wells, and installing 50 community wells. Sixty-five percent of respondents from the subset of 3410 unsafe wells changed their source of drinking water, often to new and untested wells. Only 15% of respondents from the subset of safe wells changed their source, indicating that health concerns motivated the changes. The geo-referenced data indicate that distance to the nearest safe well also influenced household responses.

Keywords: Arsenic; Groundwater; Bangladesh; Mitigation

Introduction

Over 35 million of Bangladesh's 130 million inhabitants are at increased risk for cancer, cardiovascular, neurologic, and other diseases due to naturally occurring arsenic in drinking water (Smith et al., 2000). Prior to the 1970s, contaminated surface water caused rampant diarrheal diseases throughout the country, primarily affecting children aged 1–4 (World Health Organization, 2000). The Bangladesh government and international aid organizations, spearheaded by UNICEF, then began installing tube wells that tapped into pathogen-free aquifers as an alternative water source. The convenience and low cost of installing tube wells led millions of people to install their own private well. This access to groundwater, as well as the introduction of oral rehydration therapy, was apparently effective in decreasing mortality rates (UNICEF, 1998). The unintended consequence, an epidemic of arsenicosis due to chronic arsenic exposure, became apparent in the 1990s. A decade later, it was well established that arsenic occurs naturally in groundwater in various regions throughout Bangladesh, particularly in the south and south-east (Fig. 1 and BGS and DPHE, 2001).

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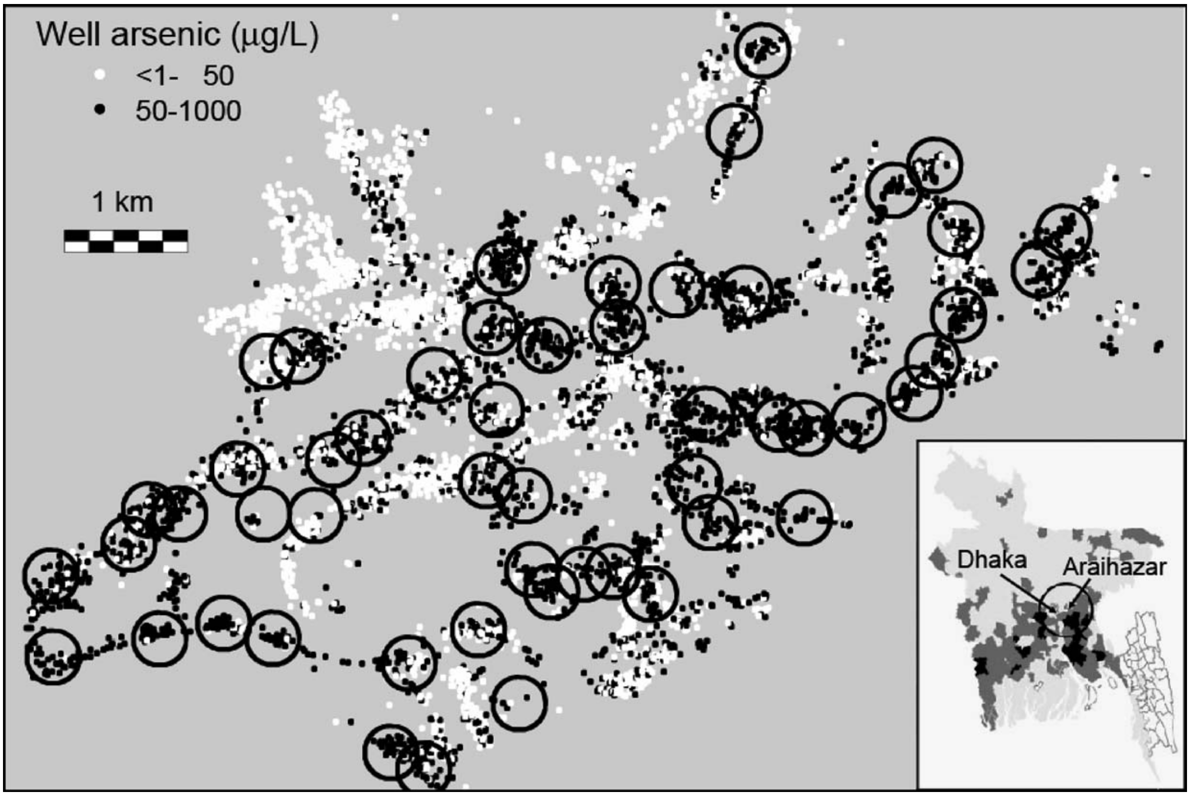


Fig. 1. Map of study area showing the distribution of safe and unsafe wells relative to the Bangladesh standard of 50 µg/L arsenic in drinking water. Large circles with a diameter of 200 m are centered on the location of each community well installed in the area. Inset shows the location of the study area relative to Dhaka, as well as the proportion of unsafe wells in various parts of the country determined by DPHE/UNICEF workers with a field kit. Shading corresponds to <20% unsafe wells (light gray), 20–80% (dark gray), and >80% (black).

At least three quarters of the estimated 10 million tube wells in Bangladesh are privately owned (BGS and DPHE, 2001; van Geen et al., 2003a). The installation of private wells continues today.

In considering solutions to the arsenic problem, many aid organizations, the Bangladesh government and researchers have proposed piping in safe water, filtering surface water through earthenware pots, chemically treating groundwater to remove arsenic, or harvesting rain water (Hanchett et al., 2001; Ahmad et al., 2003; United Nations Foundation, 1999; Cheng et al., 2004). Thus far, such relatively complex interventions have generally been less successful than some had projected, seemingly because they require more effort and/or cost than does simply using a tube well conveniently located outside the home (Caldwell et al., 2003a). Previous surveys throughout Bangladesh have indicated considerable public awareness of the hazards of arsenic in tube wells (Hanchett et al., 2001; Caldwell et al., 2003a), illustrating that public education programs effectively disseminate information. On the other hand, at least one previous study has found that a large proportion of people with unsafe wells continue using them for drinking and cooking rather than alternative water sources that were identified or provided (Hanchett et al., 2001). Such observations demonstrate the need for a better understanding of why people continue to use unsafe wells, especially when safe sources are available.

This report examines the impact of efforts to reduce arsenic exposure in a population of 70,000 in Araihazar, Bangladesh, over the past 4 years as part of an interdisciplinary research project. Mitigation focused on informing people about the level of arsenic in their well water, labeling the wells, and promoting the sharing of safe wells (van Geen et al., 2002). Deep, low-arsenic (i.e. in almost all cases <10 µg/L As) community wells were also installed, particularly in those areas with little opportunity for well switching (van Geen et al., 2003b; Gelman et al., 2004). This analysis takes into account the safety of a household's primary well, the distance to the nearest safe well, and the level of education and community involvement of the respondent. The study builds on an extensive social science household survey of 2500 people, including some of the 12,000 health cohort members, conducted in the same area in 2002 (Madajewicz et al., 2005).

Study area

The survey was conducted within a 25 km^2 area of Araihazar upazila, Bangladesh (Fig. 1). This area, which exhibits a high spatial variability in groundwater arsenic concentrations, has been subject to health, earth, and social science research to examine the health effects and origin of elevated groundwater arsenic levels, as well as potential remedies to the problem (http://superfund.ciesin.columbia.edu). Only a small fraction of the ~6000 wells in the area (94% of which are private) had been tested for arsenic prior to the launch of the project in January 2000. Nearly half the wells in the area sampled for laboratory measurements were unsafe relative to the Bangladesh drinking water standard of 50 μg/L for arsenic (van Geen et al., 2002, 2003a). An initial set of seven deep, low-arsenic community wells was installed in the area in 2001 (van Geen et al., 2003a, b).

Dates of well testing and forms of mitigation varied across the study area. An initial batch of 4999 wells in the area was sampled between March and June 2000, and analyzed by graphite-furnace atomic absorption spectrometry (van Geen et al., 2003a). In 2001, water arsenic results were communicated to individual households, metal placards were posted on each well, and the hazards of consuming unsafe well water were explained at village meetings. By the spring of 2004, when the current survey began, most well labels were missing or too rusted to read. A second batch of 1000 wells was sampled in a contiguous region in 2001 and results were communicated to individual households in 2002, though no placards were posted due to lack of affordable, durable material. A third batch of 933 wells sampled in 2003 included 352 previously tested well and 581 wells (within ~100 m) that had been either previously overlooked or recently installed (van Geen et al., 2005).

Two additional interventions occurred in 2003. Wells within the study area were painted red or green after independent testing with Hach field kits by NGO workers hired by the Bangladesh Arsenic Mitigation and Water Supply Program, supported by the World Bank (http://www.bamwsp.org/). Field test results relative to the national standard for arsenic in drinking water agreed with our laboratory tests for 88% of a randomly selected subset of 799 wells (van Geen et al., 2005). The inconsistencies were primarily underestimates in the 50–100 μg/L range of arsenic concentrations that resulted in unsafe wells being labeled as safe. Also in 2003, the number of deep, low-arsenic wells installed by the program in the study area increased from 7 to 50. The depths of the 50 low-arsenic wells ranged from 36 to 180 m; the water supplied by all but two of these wells contained less than 10 μg/L arsenic.

Methods

Collection of response data

The wife of each tube well owner, or a close female family member, was interviewed because women pump most of the water used by the entire household in Bangladesh. Our questionnaire consisted of four observations about the physical state of the well and 10 questions about characteristics of the respondent, her knowledge of the well's status, and whether the family used their well for cooking and drinking water.

Fourteen male students from the Geology Department at the University of Dhaka were trained to use Hewlett-Packard iPAQ Pocket PCs (Model h5500) fitted with NAVMAN Global Positioning System sleeves (Model 3450) to record responses and locate wells from previously recorded GPS coordinates. ESRI ArcPad 6.02 was used for navigation and data entry (http://www.esri.com). Six pairs of students collected data while the two additional students downloaded the data every evening and filled in for missing interviewers. The survey started on March 17, 2004 and ended on July 15. On average, each team interviewed 12 households in a day.

Data processing

Information collected by the six field teams was transferred to a laptop computer each evening, then compiled, unmodified, at the end of each week into a Microsoft Excel spreadsheet and e-mailed to a research team member in the US. Corrections from field notes were always evaluated and entered by the same member of the team before merging with the existing data. Distances from each unsafe well to the nearest safe private and community well were calculated with ESRI ArcView GIS 3.3.

Statistical analysis

To add to the graphical and tabular presentation of the data, Probit regressions were used to relate to the following factors the decision to switch away from a well to: a well's binary safety status; a number of binary indicators of the progressively higher well water arsenic content, in 100 μg/L intervals; the distance to the nearest safe well; years of education; and easily observable proxies for income and wealth. Additional Probit regressions consider only the behavior of those respondents that switched away from unsafe wells and focuses on the effects of the distances to the nearest safe private or community well. Consideration of the effect of education extends previous social science work in the same study area (Madajewicz et al., 2005; see additional discussion following Table 1). The insignificance of income and wealth proxies, not reported in our tables, is consistent with the previous study.

Results

Locating wells

Unexpectedly, new labels could be attached to only 68% of the 6510 previously tested wells. The remaining wells were unidentifiable because they were not located (191 wells, i.e. 3% of the total), the identification tag was missing (959, 15%), or the household confirmed moving the well since the first round of testing (964, 15%). Due to time constraints, no information was collected from relocated wells; the fraction tested by BAMWSP is therefore unknown.

A compilation of installation dates reported by the households indicates that the number of wells within the study area roughly doubled every 5 years since 1980 (Fig. 2). The third sampling campaign in 2003 revealed that there were a significant number of unrecorded and unmarked wells in the study area. Half of the wells recorded during the third survey were installed after the first two rounds; the other half had been overlooked during the earlier rounds. Extrapolation of the 170 overlooked wells installed through 1999 (that were identified in 2003) and the 165 wells installed in 2002 yield an estimate of roughly 1000 (15%) wells of unknown location and status in addition to the 6510 inventoried wells.

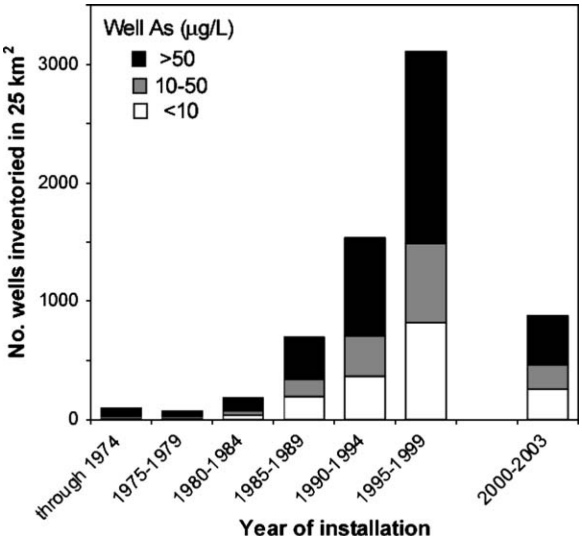


Fig. 2. History of installation and status of wells in 25 km^2 portion of Araihazar upazilla, Bangladesh. A total of 5970 wells were inventoried in 2000–2001. In 2003, survey teams returned to perform a concentrated sweep of a subset of villages. The bar showing the number of wells installed in 2000–2003 under-represents the rate of installation relative to the previous intervals because only portion of the study area was re-surveyed and because it covers a 3-year instead of a 5-year interval.

The rate of installation of new wells appears to have declined in the years that followed the testing, though not drastically so. Extrapolation from the 165 wells installed in 2002 (that were identified in 2003) in the portion of the study area covered by the samplers to the entire 25 km^2 region yields an estimated installation rate of ~1600 new wells over a 5-year period, i.e. about half the number of wells installed during the previous 5-year period (from 1994 through 1999) (Fig. 2). Tragically, the proportion of inventoried safe wells (53%) installed after 2000 was only slightly higher that for wells installed earlier (47%).

Overall responses to well testing

Communicating well status to residents significantly altered household behavior. Overall, 65% of respondents with unsafe wells switched to an alternative water source. The responses included switching to a different existing private well (55% of households that switched), drilling a new well

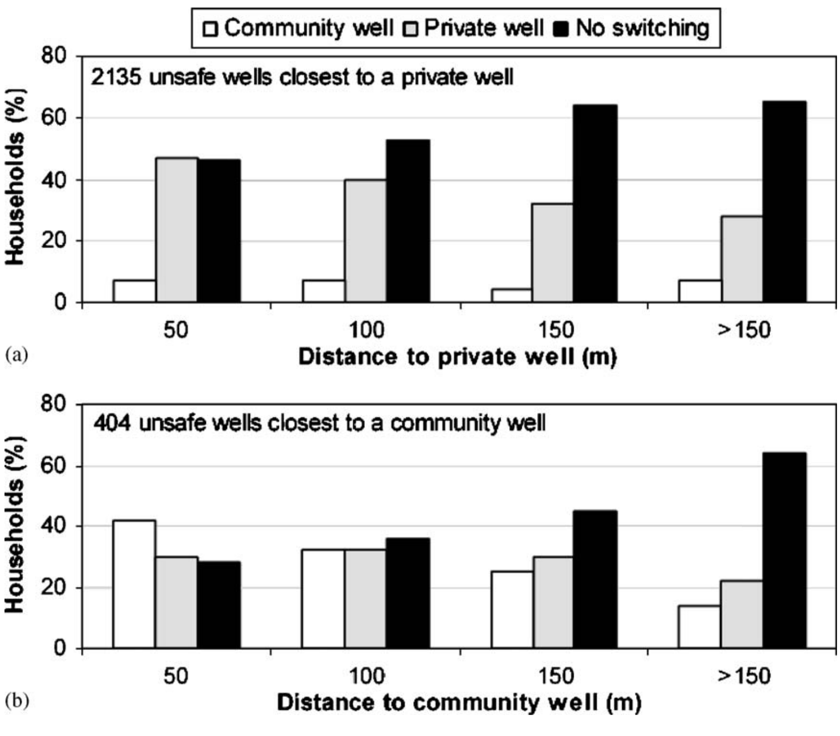
(21%), switching to the 50 community wells (16%), and switching to an undetermined source (8%). In contrast to households with unsafe wells, only 15% of respondents with safe wells switched. A non-functioning well was the main reason (40%) for switching from safe wells. Non-functioning wells are a much smaller fraction of shifts from unsafe wells. Other reasons for shifting from safe wells were unknown well safety (25%) and that BAMWSP testing had mislabeled the well as unsafe (10%), even though it was safe by Bangladesh standards for drinking water according to our laboratory measurements. The relatively modest direct contribution of community wells is not too surprising considering that only 30% of all wells in the area are located within 150 m of a community well. Of the wells located within this distance of a community well, 76% were unsafe.

Responses to different testing campaigns

Respondents whose wells were tested in the first round of sampling in 2000 showed the largest proportion of switching (69%). For wells tested in 2001 and 2003, the proportion of households switching away from an unsafe source decreased to 56% and 45%, respectively. This could reflect the time it takes for households to take seriously and respond to the news that their well is unsafe and/or could indicate that a placard reinforces the message beyond verbal information alone.

Responses to well testing as a function of arsenic level and location

In addition to whether the initial well tested "safe" or "unsafe", the degree of arsenic contamination and distance to the nearest safe well were significant determinants of household behavior. Considering functioning wells only, the proportion of switching rose gradually from 50% in the 50–150 μg/L range of As concentrations to 80% in the 450–1000 μg/L range. The proportion of households switching from unsafe wells declined steadily from 68%, when the nearest safe (private or community) well was located within 50 m, to 44% when the nearest safe well was >150 m away. The proportion of switching at large distances is surprisingly high, however. This probably reflects an overestimate of the distance to the nearest safe



(a)

(b)

Fig. 3. Responses of households initially using an unsafe well. (a) Households whose closest safe well according to the GIS is a private well. All unsafe wells closest to a community well and non-functioning wells are excluded. (b) Households whose closest safe well according to the GIS is a community well. All unsafe wells closest to a private well and non-functioning wells are excluded.

well (or untested well assumed to be safe) due to the significant number of unrecorded wells within the study area. Another indication that distance is a factor influencing behavior is that the convenience of a well closer to home is a reason frequently given by those households that installed a new well.

The estimation of distances to safe private wells or community wells provides additional information about household behavior. The number of households switching to both private and community wells dropped steadily with distance from either type of well. When a private well was the closest safe option, very few households switched to a community well (Fig. 3a). When a community well was closest, a majority of people switched to it when it was within 50 m, and the proportion of switching from unsafe wells in this category was $>70\%$ (Fig. 3b). Over and above these broad trends, there was considerable variability in the impact of individual community wells on the behavior of households whose original well was within a distance of 200 m. In 5 out of 50 villages, over 40% of the surrounding households switched to the community well whereas in as many as 12 villages not a single household reported using the community well (Fig. 4). Within the areas surrounding community wells, there is a scattered but significant relationship between proportion of households switching to a community well and the average

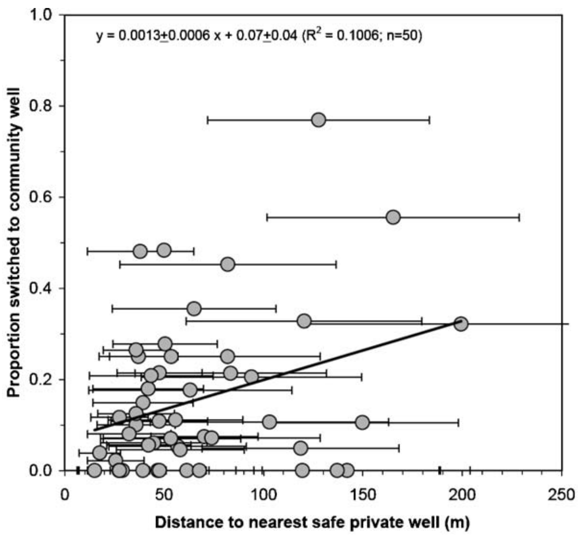


Fig. 4. Response of households with unsafe wells within 200 m of a community well ($n = 1899$) as a function of the average distance to a safe private well. Error bars indicate the standard deviation of this average distance for the area surrounding each of the 50 community wells.

distance to the nearest safe private well, suggesting a preference of a private safe well over a community well. The wide range of responses for a given average distance to a safe private well could indicate overcrowding at certain community wells, the existence of newly installed private wells whose status and location are unknown, as well as unrecorded social factors that could influence the response of a community.

Multiple regressions

The above conclusions, based on univariate analyses, were confirmed in regression analyses that controlled for other variables. Well safety status was the dominant factor that influenced switching. A model using well safety status, categories for arsenic contamination intensity, distance to the nearest safe well and years of education to explain whether a household switched wells at all is presented in Table 1. The analysis indicates that a 100 m decrease in the distance to the nearest safe well increases the probability of well switching by 18%. We also consider separately those households with unsafe initial wells who switched to some other water source, and examine determinants of choosing the private well or the community well options. For each option, the effects of the distances to the nearest private and to the nearest community wells are significant and of the expected direction. The proportion of households switching to a private well decreases with the distance to the nearest private well but increases with distance to the nearest community well (Table 2). Conversely, the proportion of households switching to a community wells decreases with the distance to the nearest community well but increases with the distance to the nearest private well. This model, however, has significantly less explanatory power than the version that includes all wells and their safety status (Table 1).

A final result of interest concerns the influence of education on household behavior (recalling that our income and wealth proxies were insignificant). Our regressions reveal that higher education increases the likelihood of switching away from an unsafe well (Table 1). The effect of education on switching to private or community wells is different, however (Table 2). A separate regression confirms that more education leads to more switching to private wells but has no effect in the case of switching to community wells. This could indicate that knowing and understanding the arsenic status of a nearby

Table 1
Regression analysis explaining the decisions to switch at all from functioning wells

Variable	Changed source[a,b,c] [marginal effects ($P>\|z\|$)]
Well safety status	.50 (.00)
Arsenic >100	.12 (.00)
Arsenic >200	.21 (.00)
Arsenic >300	.27 (.00)
Arsenic >400	.36 (.00)
Distance to the nearest safe well	−.18 (.00)
Years of education	.007 (.00)
Pseudo R^2	0.29
N	5928

[a]Removing distance, education and the measures of degree of arsenic exposure from the regression shows that the binary 'well safety status' variable is responsible for most of the explanatory power. The safety status effect can be added to the 'arsenic intensity' effects listed in the table. For instance, arsenic over 400 µg/L raises the proportion of switching by $50+36=86\%$ relative to household behavior at a safe well.

[b]'Distance to safe' has a larger effect when arsenic is not included, reflecting the significant correlation between the two variables: arsenic concentrations are higher in those villages where there are few safe wells. The distance variable is measured in hundreds of meters. Thus 100 m, or one unit, lowers the proportion of households switching by 18%.

[c]Education's coefficient implies a 8% difference in the proportion of switching between no education and finishing pre-university. This could reflect the lack of an income variable, although Madajewicz et al. (2005) found no effect of income on a binary switching variable of the type examined here (when we include income and wealth proxies there is little effect on the coefficients that are presented here, which is not surprising since there is no pattern of dependable significance for these new, financial variables). One quarter of respondents had no education. Another quarter had 5 years of education which, the model indicates, increases the proportion of switching by ~3%.

private well requires more education than switching to a community well installed and certified by an outside group. Alternatively, it may indicate that an educated (also typically richer) household with an unsafe well finds it less difficult than a poor household to convince a neighboring household to provide access to its well.

Discussion

Impact of testing

The vast majority (89%) of 6510 respondents in this survey knew the status of their well. Since a considerably smaller proportion of households with an unsafe well (65%) actually switched to a different source, most of those that did not switch did so knowingly. The results are remarkably similar to the outcome of a social science survey conducted in the area in 2002, when 60% and 14% of households with unsafe and safe wells, respectively, stated they had switched (Madajewicz et al., 2005). Evidently, the extra effort or social cost incurred in using a different private well or a community well did not result in drop in the number of households willing to switch to a different source over time. Caldwell et al. (2003b) also reported a significant proportion of switching on the basis of a national survey.

In most cases, respondents to the more recent survey indicated that they did not switch because a safe well was too far, even though many households had previously indicated that they were willing to walk comparable distances (van Geen et al., 2003b). Lack of knowledge about the arsenic content of a

Table 2
Regression analysis for functioning unsafe wells where respondents did make some switch, looking at some determinants of switching to a private well and of switching to a community well[a]

Variable	Private well [marginal effects ($P>\|z\|$)]	Community well[b] [marginal effects ($P>\|z\|$)]
Dist. to nearest private well	−.08 (.00)	.11 (.00)
Dist. to nearest community well	.14 (.00)	−.18 (.00)
Years of education	.004 (.27)	−.005 (.09)
Pseudo R^2	0.05	0.16
N	1225	1225

[a]For distance to community well to be meaningful (noting that as in Table 1 the coefficients here reflect distance measured in hundreds of meters, not meters), the sample is restricted to when a community well exists within 300 m. This restriction does not affect the conclusions for the other two determinants (note that Figs. 3a and b offer another comparison of private and community distance effects).

[b]The education results here suggest that education affects the private and community options differently. Combined with the Table 1 result they suggest, and this is confirmed in a separate regression, that more education makes people more likely to switch to private wells but it has no effect for community wells.

well, or contradictory information, also impacted household behavior. When safe wells were either mislabeled by BAMWSP or unmarked, nearly two-thirds of households installed new wells, abandoning safe wells for potentially unsafe wells. These quantitative observations indicate that determining well status correctly provides the greatest incentive for households to reduce their arsenic exposure.

Installation of new wells

Between 2000 and 2004, households continued to install new wells at a significant rate, without any indication that a higher proportion of safe wells were installed compared to previous years. Characteristics of respondents who installed new wells did not differ significantly from those who did not switch or used another well. Installing a new well implies both a preference for having one's own well and a willingness and ability to pay for it. Much of the switching to a new well is, unfortunately, uninformed because households do not have their well tested for arsenic, in many cases because they do not know where to turn to have such testing take place.

Policy recommendations

Because well safety status is a dominant factor in well-switching behavior, a strong focus of future mitigation should be to provide households the option of having their well tested and herewith ensure that wells that are correctly labeled. Unsafe wells must not be condemned altogether because a convenient source of water for washing hands still benefits basic hygiene. Since wells continue to be installed or replaced at a significant rate, providing these services locally and continuously would greatly increase the proportion of villagers that know the status of their well and act in a way that reduces exposure to arsenic. Such services would also encourage repeated testing of wells. This is important because arsenic concentrations in some wells could in principle fluctuate significantly over time, though in practice in our study area probably in only a minority of very shallow wells (Cheng et al., 2005). In addition, a small proportion of initially safe wells will inevitably fail over time, not because an entire aquifer becomes contaminated but because shallow groundwater that is elevated in arsenic can enter through faulty connections between the plastic pipes that are used to construct a well (Cheng et al., 2005).

Since many households respond when learning the status of a well, our results suggest that a concerted plan to install community wells in thousands of affected villages throughout the country could contribute to further reductions in exposure to arsenic. The vast majority of villages in Bangladesh are indeed located in areas where groundwater aquifers are safe beyond a certain depth. This is because aquifer sands deposited over 10,000 years ago and characterized by a pronounced orange color are typically associated with very low groundwater arsenic concentrations (BGS and DPHE, 2001). The complication stems from the fact that the depth to such aquifers spans a wide range in different parts of the country (<10–>500 m) and can also vary significantly from village to village (BGS and DPHE, 2001; van Geen et al., 2003a). Installing a community well to the local safe depth (Gelman et al., 2004), and informing villagers of this safe depth, could therefore have a benefit in addition to bringing a source of safe water within walking distance (van Geen et al., 2003b). Perhaps just as importantly, the information would provide those villagers that can afford it the knowledge that re-installing their own private well to that depth is likely to yield safe water.

Conclusions

This study examined the impact of arsenic mitigation in Bangladesh that consisted of informing 6500 households of the level of arsenic in their well, labeling wells, and promoting well switching. As well safety status was the most important factor affecting whether or not people switched, reliable testing services clearly could help to reduce arsenic exposure. Testing and labeling existing wells, while at the same time providing each affected village with a safe community well, could significantly decrease the number of households consuming groundwater that is elevated in arsenic.

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Human participation agreement:

This study was approved by the Columbia University IRB and the Bangladesh Medical Research Council, both of which granted permission to obtain verbal consent for this non-invasive protocol.

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