EPIDEMIOLOGY

Ensuring Safe Drinking Water in Bangladesh

Excessive levels of arsenic in drinking water is a vast health problem in Southeast Asia. Several viable approaches to mitigation could drastically reduce arsenic exposure, but they all require periodic testing.

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In the early 1980s, K. C. Saha from the School of Tropical Medicine in Kolkata attributed skin lesions in West Bengal, India, to exposure to arsenic in groundwater pumped from shallow tube wells (*1*). Despite these findings, millions of tube wells have been installed across the Bengal Basin, the geological formation that includes West Bengal and Bangladesh, and across river floodplains and deltas in southern Asia.

The popularity of tube wells reflects the reduced incidence of diarrheal disease when drinking groundwater, instead of untreated surface water, and the modest cost of installation (about 1 month of household income). Today, perhaps 100 million people in India, Bangladesh (see figure, right), Vietnam, Nepal, and Cambodia (and possibly other countries) are drinking water with arsenic concentrations up to 100 times the World Health Organization (WHO) guideline of 10 μg per liter (*2*–*4*). Whereas technologies for treating either surface water or groundwater periodically receive considerable attention, the record to date suggests that more widespread testing of wells to identify those aquifers that do not require treatment is presently far more promising.

Arsenic can occur in groundwater naturally, without an anthropogenic source. There is broad agreement that arsenic release into groundwater of the Bengal Basin is facilitated by microbial metabolism of organic matter contained in river floodplain and delta deposits (*3*–*6*). Elevated concentrations of arsenic in Bangladesh groundwater probably predate

Woman using a tube well in Araihazar, Bangladesh.

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agricultural practices that could plausibly have caused the composition of groundwater to change, such as the use of phosphate fertilizer or large groundwater withdrawals for irrigation (*3*, *7*). This does not rule out the possibility that irrigation is affecting the distribution and mobilization of arsenic today (*7*–*9*). Although there are remaining questions, current understanding of the occurrence of arsenic is sufficient to direct national strategies for lowering exposure.

After studies established the scale of the problem (*2*, *3*), a massive campaign was initiated in Bangladesh in 1999 to test tube wells in the most affected portions of the country. The field kits that were used had limitations, but were reliable enough (*10*) to identify the vast majority of tube wells that did not meet the local standard for arsenic in drinking water of 50 μg per liter. By 2005, the spouts of 1.4 million cast-iron pumps that draw groundwater with >50 μg per liter arsenic according to the field test had been painted red. Another 3.5 million wells with up to 50 μg per liter arsenic had been painted green (*11*). Such testing did not reduce the rate of private well installations, at least within areas that have been recently resurveyed (*12*, *13*). Sadly, most tube wells that were installed after the national testing campaign remain untested today.

The two interventions that have so far most effectively lowered human exposure in Bangladesh rely on the spatial heterogeneity of the distribution of arsenic in groundwater, which is controlled principally by the local geology (*3*, *14*). Testing alone had the biggest impact as ~29% of the millions of villagers informed that their tube well was elevated in arsenic have changed their water source (see the chart on page 1688). Large variations in the proportion of well-switching across villages reflect in part the availability of safe wells that are within walking distance. A recent comparison has shown, however, that both additional education and periodic reinforcement of the message that arsenic is a health hazard can overcome existing obstacles to nearly double the proportion of switching (*12*, *13*).

The intervention with the second largest impact (~12% of users with unsafe wells) has been the installation of tens of thousands of deep wells by the government and by nongovernmental organizations. Such wells supply groundwater from deeper, usually older, aquifers that generally do not contain elevated levels of arsenic (*3*, *14*, *16*). They are often shared or community wells that require walking ~100 m several times a day. Yet these wells can be very popular when placed in a central location that, for instance, does not discourage use by women. These community installations have also had an indirect impact because numerous households followed suit by reinstalling their own well to greater depth (*12*, *13*).

In 2004, Bangladesh issued a National Policy for Arsenic Mitigation (NPAM) accompanied by a more detailed Implementation Plan for Arsenic Mitigation (*17*). Well-switching was recognized by the NAPM in the sense that alternative water supply was not proposed for villages where <40% of tube wells are unsafe. However, the NPAM considered deep tube wells a low-priority option. Instead, the document encouraged a return to the use of surface or very shallow groundwater without paying sufficient attention to the increased likelihood of exposure to microbial pathogens.

Five other mitigation approaches promoted by the NPAM have had a limited impact, each reaching <1% of the population at risk (see the chart on page 1688). The early record of

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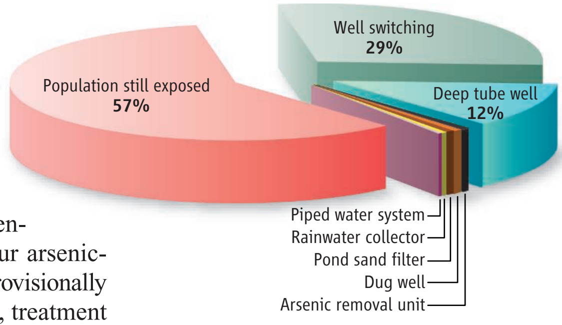
arsenic removal from groundwater by adsorption and/or coprecipitation is mixed. Failures have arisen from inadequate removal due to the challenging composition of the groundwater, logistical difficulties in ensuring proper maintenance, and inconvenience to the users (*18*). Since four arsenic-removal technologies have been provisionally approved for marketing, however, treatment may become more widespread. Dug wells are used by thousands of villagers. Although the shallowest aquifers tapped by these wells are typically low in arsenic, a full-scale return to this traditional technology is hampered by concerns regarding the microbial quality of the water and the need for regular maintenance (*16*). Treatment of pond or river water by sand filtration, a priority in the 2004 NPAM, appears less promising. Ponds often directly receive human waste from surrounding latrines and are increasingly used for aquaculture. Also, as industry develops throughout rural Bangladesh, sand filtration alone is unlikely to guarantee a treatment suitable for human consumption. Rainwater harvesting by individual households can provide safe drinking water. Its main drawbacks are the potential for microbial contamination and the high cost of storage sufficient for Bangladesh's 8-month dry season. Last, piped-water supply is frequently touted as the solution to the arsenic problem. The high capital and maintenance costs of such systems relative to those of individual tube wells, however, is likely to restrict this approach to urban areas or the most affluent villages.

Recommendations

More than half of the population in Bangladesh at risk from arsenic is still exposed (see chart, above). To reach a greater fraction of the population, we urge a revision of the NPAM to (i) stimulate the periodic monitoring of water quality no matter the mitigation option, (ii) encourage rather than discourage the wise use of deep aquifers that are low in arsenic, and (iii) include the newly demonstrated effects of arsenic on the mental development of children in information campaigns (*19*).

Periodic field testing of numerous point sources of drinking water would be an enormous challenge for any government. We recommend consideration of alternative programs for well testing, in particular a national certification program to license and monitor entrepreneurs offering commercial field testing to villages. Ideally, test results should indicate actual concentrations. Households have used this information to reduce arsenic exposures even without access to a safe well. The cost of testing tube wells for arsenic is significant (~$1 per test) but is even higher for other water-supply options that require water treatment, because the performance of such systems is more likely to vary over time. Dug wells, for instance, should be tested monthly for microbial contamination, which is a considerably more difficult measurement than a field test for arsenic.



Impact of arsenic mitigation in Bangladesh (SOM Text). The initially exposed population has been estimated at 28 to 35 million relative to the local standard of 50 μg per liter arsenic in drinking water (*3*).

As the population of Bangladesh continues to grow, many shallow wells are likely to become contaminated with human, agricultural, and industrial waste. In addition, groundwater pumped from a majority of shallow tube wells is naturally elevated in manganese, another constituent of increasing health concern because of its neurological effects (*3*, *20*). Several field kits are available to determine whether a well meets the WHO guideline of 0.4 mg per liter for manganese. The systematic use of these field kits for testing shallow and deep wells should be considered, even if the health implications of exposure to manganese present in groundwater are not yet fully understood.

Groundwater from deep wells is a good source of drinking water in many parts of Bangladesh because it does not require treatment. Deep wells nevertheless should be tested at least once a year, as a small fraction are likely to fail over time. Presently, not even deep wells installed by the government are periodically tested for arsenic. One source of confusion has been that the depth to older aquifers that are systematically low in arsenic varies from <30 m to >200 m across the country and can vary even between adjacent villages (*3*, *21*). Thus, the depth to aquifers that are low in arsenic must be determined at the village level and attempts to establish the depth to low-arsenic aquifers over larger areas are misguided.

We believe that significant contamination of deep aquifers with arsenic is unlikely unless large amounts of water are withdrawn for irrigation (*22*). Managing irrigation is therefore important. Although the incorporation of arsenic into rice that has been grown on shallow groundwater appears to be limited (*23*, *24*), potential long-term effects of irrigating with groundwater that is elevated in arsenic should be monitored.

In summary, water testing must be drastically expanded in Bangladesh. Eight years after a major arsenic conference in Dhaka, millions of people continue to drink groundwater containing toxic levels of arsenic. Without discouraging any option, the NPAM should be revised soon after the upcoming elections to expand the scale of those interventions that have been most effective to date.

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Supporting Online Material for

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This PDF file includes

Fig. S1
Table S1
References

Table S1. Estimated impact of various forms of arsenic mitigation in Bangladesh and measures of microbial contamination of these sources. The compilation relies primarily on reports from the Arsenic Policy Support Unit with additional information from other listed studies.

New water source	No. installed	Users/unit[6]	Estimated impact[1] % of population at risk	*E. coli* /100 mL[7] dry/wet season (n)
Nearby private well[2]	-	-	29	-
Deep tubewell[3]	74,809	50	12	0/0 (36)
Arsenic removal unit[4]	33,074	6	0.66	-
Dug well[3]	6,268	30	0.63	138/657 (36)
Pond sand filter[3]	3,521	50	0.59	31/51 (34/42)
Rainwater collector[3]	13,324	6	0.27	12/1 (24/42)
Piped water system[5]	65	240	0.05	-

[1]BGS/DPHE estimate a range of 28-35 million exposed to >50 ug/L arsenic (*S1*). R. Johnston of UNICEF (pers. comm., 2006) estimates a total of 20 million at risk based on the basis of BAMWSP population and field kit data, corrected for kit bias.

[2]In a highly studied area with 47% unsafe wells, 55% of 2539 households switched to a nearby private well (*S2*, *S3*). In an area with 52% unsafe wells where only BAMWSP/DPHE intervened, 29% of 2087 households switched (*S4*). Testing and mitigation in 3 upazilas with 77% unsafe wells under UNICEF led to switching by 38% of 6359 households (Table 5.18 in ref. *S5*).

[3]From Table 1.1 in ref. (*S6*). The deep wells referred to in this context are distinct from shallow irrigation wells equipped with a submersible pump, also sometimes referred to as deep wells in Bangladesh although the term “deep-set” tubewells would be more appropriate.

[4]Includes 3,771 households units reported in ref. (*S6*) and 29,303 SONO units deployed according to A. Hussam (pers. comm., 2006)

[5]Includes 33 pipe water supplies systems fed with deep tube well water reported in (*S6*), serving an estimated population of 240, and 27 systems fed with dug well water (pop. 4400), and 5 systems fed by river filtration system (pop. 3200) installed by Dhaka Community Hospital (R. Wilson, pers. comm., 2006).

[6]Estimated average. Number of users per unit varies widely for community sources (*S6*, *S7*).

[7]Mean values from Tables 4.1-4.4 in ref. (*S6*).

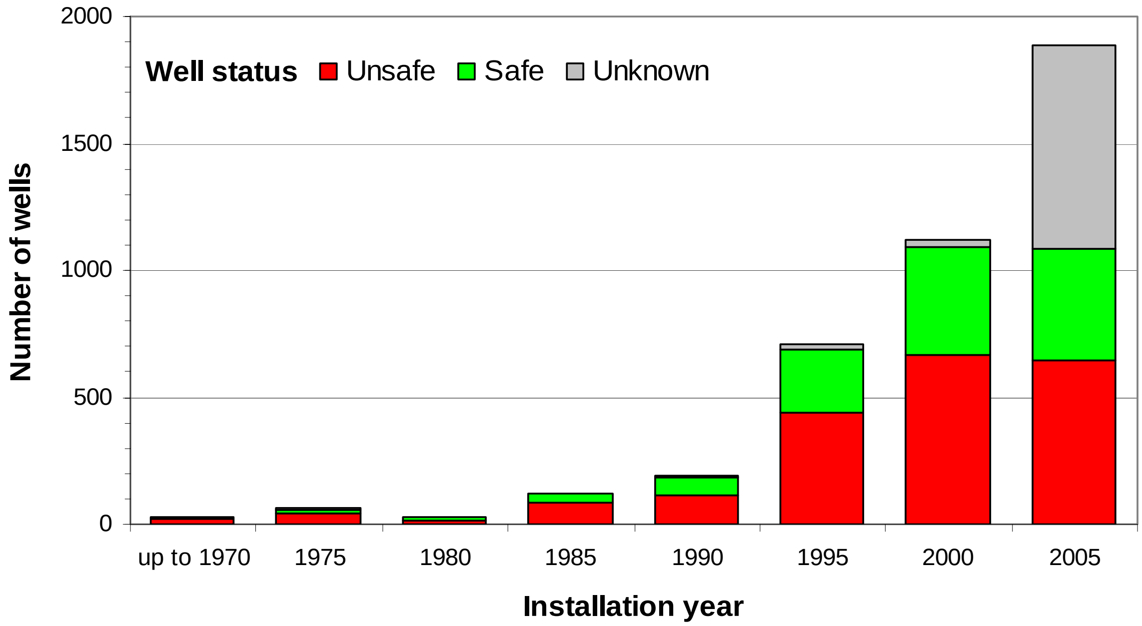

Fig. S1. Histogram of the year of installation of tubewells compiled in 2005 within 75 villages of Araihazar upazila, Bangladesh, where the only significant intervention has been blanket-testing for arsenic, carried out with field kits in 2003 (*S4*). Well status information with respect to arsenic based on field kit measurements was compiled during the survey on the basis interviews and the color of the paint applied to the spout of each well (or lack thereof). The rate of installation of wells documented in this survey should be representative of the estimated total of ~10 million wells installed in the country as a whole (*S1*, *S8*).

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