

Promotion of well-switching to mitigate the current arsenic crisis in Bangladesh

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Objective To survey tube wells and households in Arai-hazar *upazila*, Bangladesh, to set the stage for a long-term epidemiological study of the consequences of chronic arsenic exposure.

Methods Water samples and household data were collected over a period of 4 months in 2000 from 4997 contiguous tube wells serving a population of 55 000, the position of each well being determined to within ± 30 m using Global Positioning System receivers. Arsenic concentrations were determined by graphite-furnace atomic-absorption spectrometry. In addition, groundwater samples collected every 2 weeks for an entire year from six tube wells were analysed for arsenic by high-resolution inductively coupled plasma-mass spectrometry.

Findings Half of the wells surveyed in Arai-hazar had been installed in the previous 5 years; 94% were privately owned. Only about 48% of the surveyed wells supplied water with an arsenic content below 50 $\mu\text{g/l}$, the current Bangladesh standard for drinking-water. Similar to other regions of Bangladesh and West Bengal, India, the distribution of arsenic in Arai-hazar is spatially highly variable (range: 5–860 $\mu\text{g/l}$) and therefore difficult to predict. Because of this variability, however, close to 90% of the inhabitants live within 100 m of a safe well. Monitoring of six tube wells currently meeting the 50 $\mu\text{g/l}$ standard showed no indication of a seasonal cycle in arsenic concentrations coupled to the hydrological cycle. This suggests that well-switching is a viable option in Arai-hazar, at least for the short term.

Conclusions Well-switching should be more systematically encouraged in Arai-hazar and many other parts of Bangladesh and West Bengal, India. Social barriers to well-switching need to be better understood and, if possible, overcome.

Keywords Potable water/chemistry/standards; Water supply/analysis; Arsenic; Bangladesh (*source: MeSH, NLM*).

Mots clés Eau potable/composition chimique/normes; Alimentation eau/analyse; Arsenic; Bangladesh (*source: MeSH, INSERM*).

Palabras clave Agua potable/química/normas; Abastecimiento de agua/análisis; Arsénico; Bangladesh (*fuentes: DeCS, BIREME*).

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Introduction

In Bangladesh approximately 30–36 million people are currently chronically exposed to high levels of arsenic ($>50 \mu\text{g/l}$) in drinking-water derived from groundwater supplied by millions of hand-pumped tube wells (1). Installation of these wells has been promoted in Bangladesh as a means of reducing childhood mortality from waterborne microbial diseases caused by drinking contaminated surface waters. However, cancers of the skin, liver, lungs and other internal organs, as well as diabetes and cardiovascular diseases induced by the presence of arsenic in tube-well water will contribute to a major human tragedy over the next several

decades (2). National and international programmes to reduce arsenic exposure have so far been largely ineffective, even though the serious nature of the regional situation was reported in the mid-1980s in West Bengal (3) and in the mid-1990s in Bangladesh (4). Testing a small fraction of the millions of existing wells has shown that, despite evidence of some broad regional patterns (1), it has been impossible to predict on a local scale whether a particular well will yield water that is safe or has an elevated arsenic level. The Bangladesh drinking-water standard for arsenic is 50 $\mu\text{g/l}$; for comparison, the WHO guideline level is 10 $\mu\text{g/l}$ (5, 6). Our survey of contiguous wells within an area that encompasses patterns of geographical

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arsenic variability that are similar across broad regions of Bangladesh (1) indicates that, while the nature of the arsenic distribution complicates intervention, the high degree of spatial variability also presents an opportunity for remediation that needs to be more widely encouraged and stimulated.

Methods

Water samples were collected from 4997 contiguous tube wells in Araihaazar *upazila*, Bangladesh, 25 km east of Dhaka, from March to June 2000, as part of a long-term epidemiological study of arsenic exposure. The study was undertaken alongside an investigation of the origin of elevated dissolved arsenic and of various remedial strategies (7). Using a questionnaire, we collected the following information for each well: number of users, household composition of users, the date of installation, and the depth of the well. Questions were also asked to gauge the respondents' awareness of the risks associated with elevated arsenic in tube-well water and their preferences for different remedial options should the well turn out to be unsafe. Hand-held Global Positioning System (GPS) receivers were used to determine the location of each well, in most cases to within ± 30 m (Fig. 1). After continuously pumping each well for 5 minutes, we collected a sample of water into an acid-cleaned polyethylene bottle and acidified it immediately to 1% (v/v) hydrochloric acid. Blanks,

replicates, and replicate samples with standard additions were similarly processed approximately every 20 samples. Total arsenic was determined at Columbia University by graphite-furnace atomic-absorption spectrometry with an estimated accuracy of $\pm 10\%$, based on the reproducibility of the standard additions in the field, over a dynamic range of concentrations spanning more than two orders of magnitude (<5 – $860 \mu\text{g/l}$). Six wells located within the study area producing water with an arsenic content of $<50 \mu\text{g/l}$ were sampled every 2 weeks for an entire year. These samples were analysed for arsenic by high-resolution inductively coupled plasma–mass spectrometry to obtain a high-precision time series at these lower levels.

Results

The contiguous wells that were sampled cover an irregularly-shaped area of approximately 21 km^2 and serve a population of approximately 55 000. The wells are clustered in villages separated by open rice fields (Fig. 1). The number of wells in the study area has roughly doubled every 5 years (Fig. 2), with an annual growth rate of 15%, more than five times greater than that of the annual population increase in Bangladesh. The vast majority of the study wells are privately owned (94%) and were installed by small local companies (Table 1). When asked, 57% of the respondents indicated some

Fig. 1. Distribution of arsenic in 4997 tube wells in Araihaazar *upazila*, Bangladesh. Within the subarea demarcated by the small rectangle, 89% of the wells are within 200m of a safe well, even though only 18% of the wells yield water containing $\leq 50 \mu\text{g/l}$ arsenic. The centres of the large open circles correspond to the locations of six tube wells that were monitored every two weeks for one year

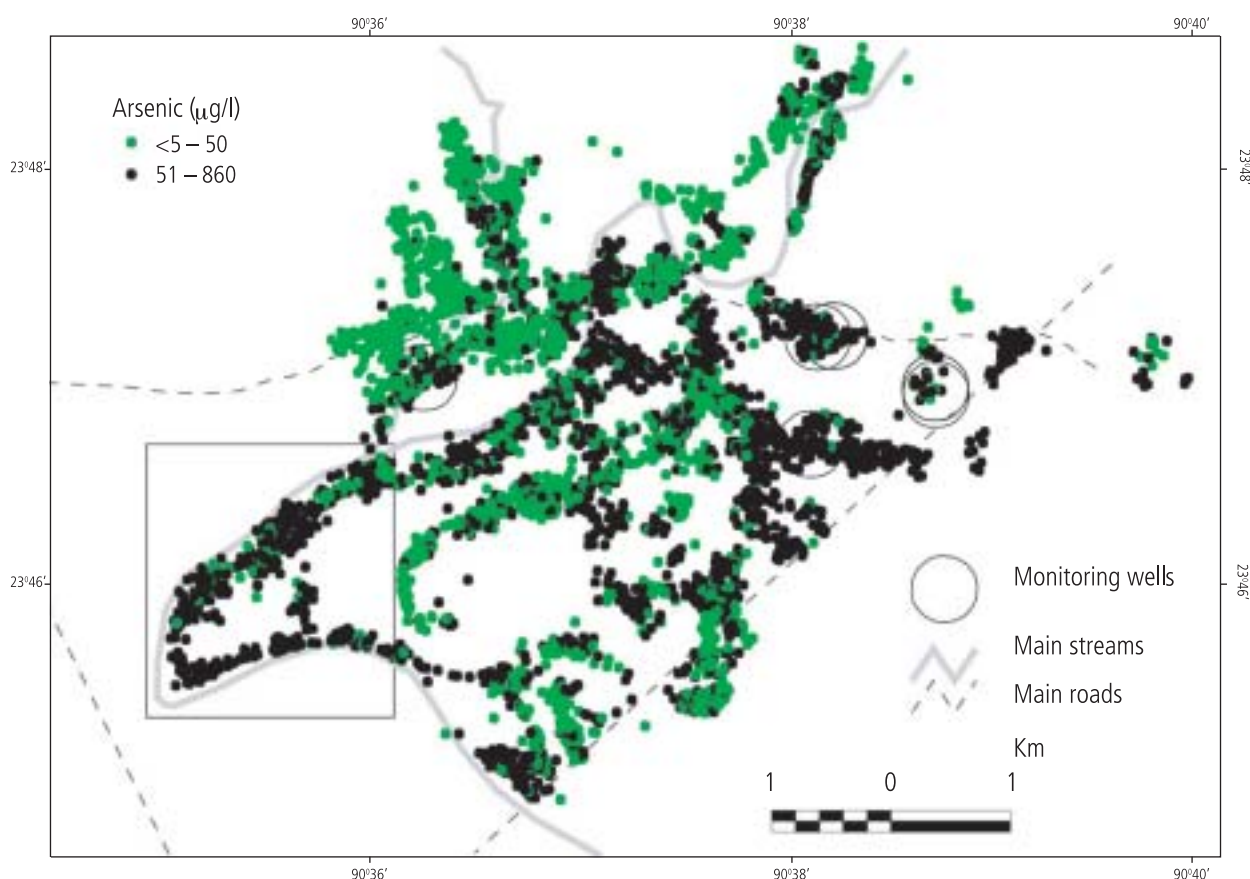


Fig. 2. Plot showing proliferation of tube wells from 1970 to 2000 in the 21-km² area of Araihaazar, Bangladesh, from which samples were collected (not all the wells installed in 2000 were sampled by the time the survey ended in June 2000)

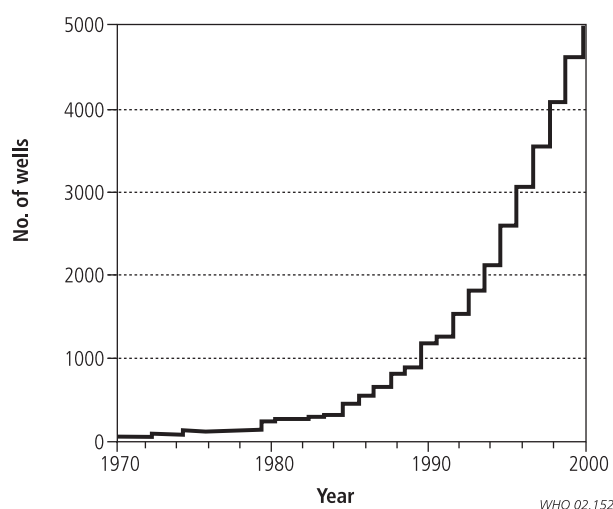


Table 1. Funding source of tube wells (*n* = 4997), Araihaazar, Bangladesh, 2000

Source	% of total
Private	94
Government ^a	3
Mosque, bazaar, or nongovernmental organization	3

^a Including UNICEF and other international organizations.

knowledge of the health risks associated with drinking tubewell water with an elevated arsenic content. But for reasons that need to be better understood, efforts to inform the population of these risks over the past 5 years do not seem to have affected the rate of well installation. In this area each well has an average of 11 users. Extrapolating these data to the entire country indicates that the number of wells installed throughout Bangladesh may have increased from approximately 6 million to 12 million since 1995, a time when the magnitude of the arsenic problem was already well established. The density of wells in Araihaazar may be higher than elsewhere in the country, however. The proportion of households that can afford a tube well may be particularly high in Araihaazar due to the additional income generated by numerous textile factories in the area.

Only 48% of the nearly 5000 wells that were sampled in Araihaazar met the current Bangladesh drinking-water standard for arsenic of $50 \mu\text{g/l}$ (Table 2). This proportion is consistent with the location of Araihaazar at the boundary between a broad swathe of wells with elevated arsenic content that crosses the country to the south, and a region to the north where wells are largely safe (1). Over one-third of the population in Araihaazar is exposed to arsenic levels that exceed the Bangladesh drinking-water standard by a factor of at least two (Table 2). There is considerable variation in the proportion of safe and unsafe wells within the study area, with a

Table 2. Range of concentration of arsenic in water from 4997 tube wells in Araihaazar, Bangladesh, 2000

Arsenic concentration ($\mu\text{g/l}$)	% of wells
< 5–10	28
11–50	20
51–100	17
101–900	35

higher proportion of safe wells in the central region and very few safe wells to the east and to the west (Fig. 1). Similar patterns of variability on a local scale have been reported elsewhere in Bangladesh (1).

About 4% of all the wells that were surveyed were reported to have been tested previously (Table 3), with almost all these tests having been conducted over the previous 3 years. The results from these tests, as recalled by the respondents, agreed with the laboratory measurements for our samples, collected at a later date, in 63% of the cases where the respondents recalled that the well had been declared safe; and in 74% of cases where wells had been declared unsafe. A significant proportion of the respondents did not know the outcome of previous tests of their well. Clearly, the quality of field test results needs to be improved and their outcome more clearly conveyed to the local population (8).

Because the position of all wells was determined in the present study, the distance from each unsafe well to the nearest safe well could be calculated. This analysis revealed that even though only half the inhabitants of the study area had access to safe water from their own well, 88% resided within 100 m of a safe well and 95% within 200 m (Fig. 3). Even for a subset of 515 contiguous wells of which only 18% were safe (Fig. 1), 73% of the villagers concerned lived within 100 m of a safe well and 89% within 200 m. The implication of this finding is that well-switching could drastically reduce arsenic exposure in Araihaazar, and possibly in many other parts of the country, at least in the short term. Well-switching was also the remedial option selected most frequently by respondents to the questionnaire (Table 4). While a significant proportion of the respondents indicated their preference for other options, few said they would not respond in any way if their well turned out to be unsafe.

The question remains as to whether the population in the study area can be safely redirected to tube wells producing water with an arsenic content of $<50 \mu\text{g/l}$. The six currently safe wells that were sampled more frequently over a year showed no indication of significant seasonal fluctuations in arsenic concentrations (Fig. 4b) and only one of the time-series samples exceeded the Bangladesh standard for drinking-water. The slightly higher arsenic concentration in that sample could be due to the entrainment of a few particles of aquifer material followed by its partial dissolution upon acidification, since samples were collected without filtering. Overall, the available data do not show evidence of significant short-term fluctuations in low-arsenic groundwater in Araihaazar.

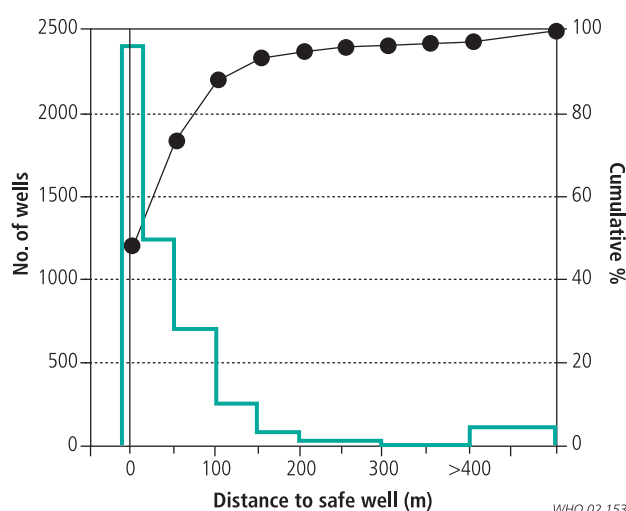
Discussion

Even though well-switching is implicit in current efforts to paint tube wells red or green throughout Bangladesh in

Table 3. Comparison of laboratory determinations of the arsenic content of water from tube wells, Arai-hazar, Bangladesh, with respondents' recollection of previous determinations performed in the study area

Water category	% who recalled previous results, by arsenic level:	
	$\leq 50 \mu\text{g/l}$	$> 50 \mu\text{g/l}$
Safe ($n = 115$)	63	37
Unsafe ($n = 85$)	27	73
Don't know ($n = 56$)	48	52

Fig. 3. Plot showing number of wells as a function of the distance from each well to the nearest safe well, in increments of 50 m. The number of safe wells shown as green dots in Fig. 1 are depicted as a narrow peak centred on 0 m. Also shown is the cumulative proportion of tube wells within each distance interval



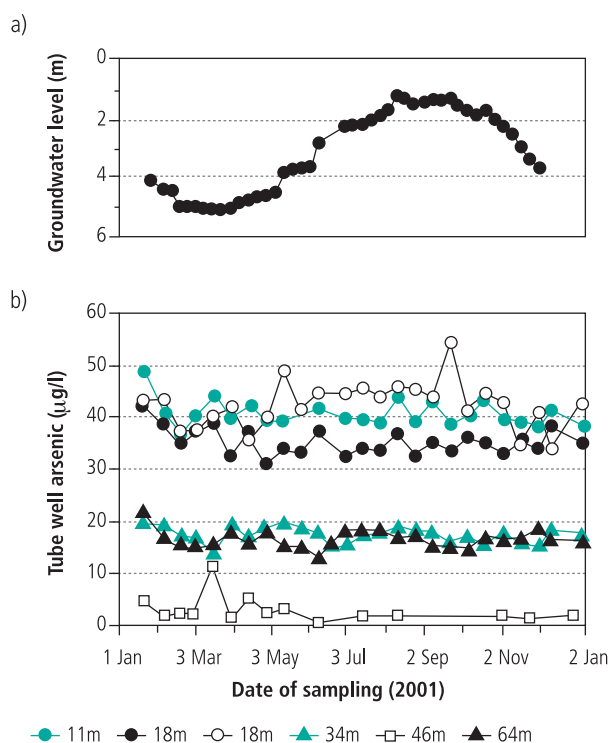
accordance with results from arsenic tests performed in the field, this form of remedial action has not been aggressively promoted by national and international programmes addressing the arsenic crisis. This may be because GPS data are infrequently collected in such surveys, which precludes quantitative analysis of the patchiness of the arsenic distribution. Instead, options that require more investment, know-how and monitoring, such as arsenic removal systems or the installation of deeper tube wells, have received more attention (1, 8).

How applicable is well-switching elsewhere in Bangladesh? Spatial variability in tube-well arsenic has previously been documented in three special study areas: Lakshmipur, Fardipur and Chapai Nawabganj (1), although not by sampling all contiguous wells. As in Arai-hazar, monitoring of arsenic concentrations in 36 tube wells in the same special study areas over the course of a year did not show any notable temporal fluctuations (9). Well-documented time-series such as these will be crucial in examining any systematic increases in groundwater arsenic over the long term in response to human activities, e.g. pumping of groundwater for irrigation. These considerations, combined with our distance calculations within Arai-hazar, suggest that

Table 4. Remedial option preferred by respondents using tube wells with a high arsenic content in Arai-hazar, Bangladesh ($n = 4997$ wells)

Option	%
Switch to nearby safe well	43
Treat well water/deepen well	31
Surface water with/without treatment	20
No action or missing data	6

Fig. 4. a) Variations in groundwater level in the Arai-hazar study area over the course of one year, based on measurements inside a monitoring well screened at 6 m below the surface. b) Time series of groundwater arsenic levels for the six private tube wells shown in Fig. 1 that met the Bangladesh drinking-water standard of $50 \mu\text{g/l}$ (well depths below the ground surface are also shown)



well-switching could be a viable option for significantly reducing arsenic exposure in the short term in all but 29 *upazilas* in Bangladesh where $>80\%$ of the wells produce water with an arsenic content of $>50 \mu\text{g/l}$. These most affected *upazilas* have been identified on the basis of 51 000 field tests conducted jointly by the Department of Public Health Engineering and UNICEF as of October 1999 in 391 of the 460 *upazilas* in Bangladesh.

There are undoubtedly significant socioeconomic barriers to well-switching, since most wells are privately owned (10). Such obstacles need to be examined more closely to assess whether they can be reduced. Women, for instance, are traditionally not expected to leave their *bari* (a cluster of related households) unaccompanied. Privacy is another issue since many of the tube wells are installed near the household's latrine. Crowding around safe wells does not seem to be a

major issue, at least in Araihaazar. The number of users per safe well will necessarily increase if half the existing wells are no longer used to supply water for drinking or cooking. Calculations based on our survey indicate, however, that the density of users at each well already spans a considerable range (Fig. 5a). Overall, the density of users would therefore not be as drastically altered as might be expected if each household with an unsafe well were to switch to the nearest safe well in Araihaazar (Fig. 5b).

Conclusion

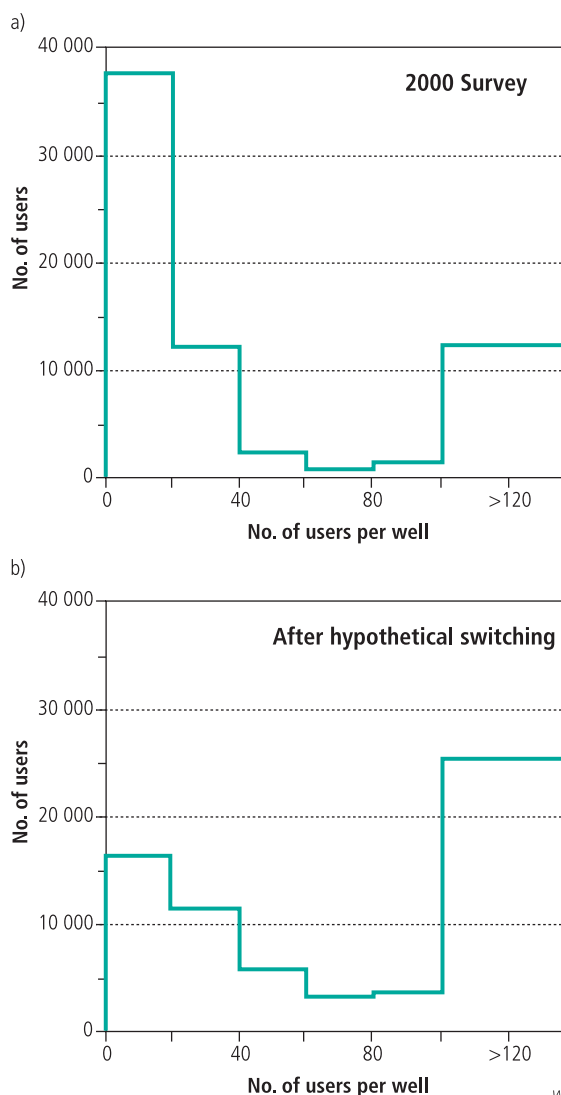
Our findings indicate that well-switching should figure more prominently on the list of remedial options that are urgently needed to address the arsenic crisis in Bangladesh and West Bengal, India. Although there are presently no indications of significant short-term changes in groundwater arsenic concentrations, a subset of representative wells should be carefully monitored to detect any potential changes over the long term. Since small private companies have installed the vast majority of wells in Bangladesh, providing these companies with arsenic field kits seems worth considering. Coupled to an independent quality-control programme run by government or nongovernmental organizations, well-installing companies may be the best hope of identifying the millions of safe and unsafe wells that remain to be analysed throughout the country, since large numbers of wells continue to be installed or re-positioned. Market forces could also induce these same companies to combine their knowledge of the local geology with the arsenic measurements to develop strategies for targeting safe aquifers. ■

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Conflicts of interest: none declared.

Fig. 5. a) Number of well-users as a function of user density during the 2000 survey shown in increments of 20 users per well. b) Number of well-users as a function of user density following a hypothetical switch of each household with an unsafe well to the nearest safe well. The integrated number of users is 65 000 rather than the resident population of 55 000 because of multiple user counts at community wells and at wells located near mosques and factories



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Résumé

Promotion de changement d'utilisation de puits afin de réduire l'exposition à l'arsenic au Bangladesh

Objectif Réaliser une enquête sur les puits et les ménages dans l'*upazila* d'Araihaazar (Bangladesh) afin de préparer une étude épidémiologique de longue durée sur les conséquences de l'exposition chronique à l'arsenic.

Méthodes Des échantillons d'eau et des données sur les ménages ont été recueillis pendant quatre mois pour 2000 puits sur les 4977 puits contigus desservant une population de 55 000 personnes. La position de chaque puits a été déterminée à 30 mètres près à l'aide de récepteurs GPS (Global Positioning System). Les concentrations en arsenic ont été mesurées par spectrophotométrie d'absorption atomique à four graphite. En outre, des échantillons d'eau souterraine recueillis toutes les deux semaines pendant une année entière dans six puits ont fait l'objet d'un dosage de l'arsenic par

spectrométrie de masse à haute résolution avec source plasma à couplage inductif.

Résultats La moitié des puits enquêtés à Araihaazar avaient été installés au cours des cinq années précédentes ; 94 % d'entre eux étaient privés. Seuls 48 % des puits enquêtés donnaient une eau contenant moins de 50 µg/l d'arsenic, norme en vigueur au Bangladesh pour l'eau potable. Comme dans d'autres régions du Bangladesh et du Bengale-Occidental (Inde), l'arsenic a une distribution spatiale très inégale (entre 5 et 860 µg/l) et par conséquent difficile à prévoir. Toutefois, en raison même de cette variabilité, près de 90 % des habitants vivent à moins de 100 m d'un puits sain. La surveillance de six puits répondant actuellement à la norme de 50 µg/l n'a montré aucun indice de cycle saisonnier

de l'arsenic en relation avec le cycle hydrologique. Ces observations laissent à penser que les changements de puits sont une option viable à Araihaazar, au moins à court terme.

Conclusion Les changements de puits existants devraient être plus systématiquement encouragés à Araihaazar et dans de

nombreuses autres parties du Bangladesh et du Bengale-Occidental (Inde). Les barrières sociales faisant obstacle aux changements de puits doivent être mieux connues et si possible surmontées.

Resumen

Promoción del uso de pozos seleccionados para reducir la exposición al arsénico en Bangladesh

Objetivo Hacer un análisis sobre los pozos y los hogares de la *upazila* de Araihaazar (Bangladesh), a fin de sentar las bases para llevar a cabo un estudio epidemiológico a largo plazo sobre las consecuencias de la exposición crónica a arsénico.

Métodos Durante un periodo de 4 meses de 2000, se obtuvieron muestras de agua a partir de 4997 pozos cercanos que abastecían a una población de 55 000 personas, y se reunieron datos de los hogares próximos; la situación de cada pozo se determinó con una precisión de ± 30 m utilizando receptores del Sistema Mundial de Determinación de la Posición. Las concentraciones de arsénico se analizaron mediante espectrometría de absorción atómica en horno de grafito. Se analizó asimismo la presencia de arsénico en muestras de agua subterránea recogidas cada 2 semanas durante todo un año en seis pozos, empleando para ello la técnica de espectrometría de masas de alta resolución por plasma de acoplación.

Resultados La mitad de los pozos examinados en Araihaazar habían sido practicados en los 5 años anteriores, y el 94% eran

privados. Sólo un 48% de los pozos suministraban agua con un contenido de arsénico inferior a 50 µg/l, el límite fijado actualmente en Bangladesh para el agua potable. Al igual que en otras regiones de Bangladesh y Bengala occidental (India), la concentración de arsénico en Araihaazar varía mucho de un lugar a otro (intervalo: 5–860 µg/l), y es por tanto difícil de predecir. Debido a esa variabilidad, sin embargo, casi un 90% de los habitantes vive a menos de 100 m de un pozo salubre. La vigilancia de seis pozos que actualmente se ajustan al límite mencionado de 50 µg/l no reveló ningún dato que sugiriera la existencia de un ciclo estacional de las concentraciones de arsénico paralelo al ciclo hidrológico. Esto lleva a pensar que el cambio de pozos constituye una opción viable en Araihaazar, al menos como solución a corto plazo.

Conclusión Es preciso fomentar de manera más sistemática el uso de pozos seleccionados en Araihaazar y en muchas otras partes de Bangladesh y Bengala occidental (India), y hay que conocer mejor las barreras sociales con que tropieza esa iniciativa para superarlas en la medida de lo posible.

References

1. *Groundwater studies for arsenic contamination in Bangladesh. Main report.* Dhaka: Department of Public Health Engineering, Mott MacDonald Ltd; and British Geological Survey, 1999.
2. Smith AH, Lingas EO, Rahman M. Contamination of drinking-water by arsenic in Bangladesh: a public health emergency. *Bulletin of the World Health Organization* 2000;78:1093-103.
3. Chakraborty AK, Saha KC. Arsenic dermatosis from tubewell water in West Bengal. *Indian Journal of Medical Research* 1987;85:326-34.
4. Dhar RK, Biswas BK, Samanta G, Mandal BK, Chakraborti D, Roy S, et al. Groundwater arsenic calamity in Bangladesh. *Current Science* 1997;73:48-59.
5. *Guidelines for drinking-water quality*, 2nd ed. Vol. 2: *Health criteria and other supporting information*. Geneva, World Health Organization; 1996. P. 940-9.
6. *Guidelines for drinking-water quality*, 2nd ed. Addendum to Vol. 2: *Health criteria and other supporting information*. Geneva, World Health Organization; 1998. p. 281-3.
7. Health Effects and Geochemistry of Arsenic and Lead. NIEHS/EPA Superfund Basic Research Program. Details available from: URL: <http://superfund.cie-sin.columbia.edu/>
8. *Combating a deadly menace: Early experiences with a community-based arsenic mitigation project in Bangladesh.* Dhaka: Bangladesh Rural Advancement Committee; 2000. Research Monograph Series, No. 16.
9. Kinniburgh DG, Smedley PL, editors. *Arsenic contamination of groundwater in Bangladesh*, Vol. 2, Final Report. Keyworth: Engalnd; British Geological Survey. BGS Technical Report WC/00/19.
10. Hanchett S, Nahar Q, van Agthoven A, Geers C, Rezvi MFJ. *Arsenic awareness in six Bangladesh towns.* Dhaka: 18 District Towns Water Supply, Sanitation, and Hygiene Education Project; 2000.