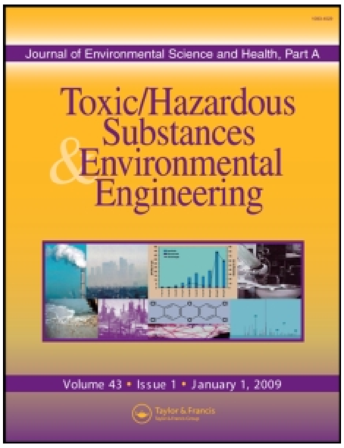

Journal of Environmental Science and Health, Part A
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713597268

Arsenic concentrations and bacterial contamination in a pilot shallow dugwell program in West Bengal, India

Meera M. Hira-Smith [a]; Yan Yuan [a]; Xavier Savarimuthu [b]; Jane Liaw [a]; Alpana Hira [c]; Cynthia Green [d]; Timir Hore [e]; Protap Chakraborty [f]; Ondine S. von Ehrenstein [a];Allan H. Smith [a]
[a] School of Public Health, University of California, Berkeley, CA, USA [b] Department of Environmental Science, St. Xavier's College, Kolkata, India [c] Department of Geography, Shibpur Dinobundhu (Institution) College, Howrah, India [d] Masters candidate, Environmental and Water Resources Engineering, University of Texas, Austin, Texas, USA [e] C&H Environmental, Inc., Hackettstown, New Jersey, USA [f] Former Director, Geological Survey of India, Kolkata, India

To cite this Article Hira-Smith, Meera M. , Yuan, Yan , Savarimuthu, Xavier , Liaw, Jane , Hira, Alpana , Green, Cynthia , Hore, Timir , Chakraborty, Protap , von Ehrenstein, Ondine S. andSmith, Allan H.(2007) 'Arsenic concentrations and bacterial contamination in a pilot shallow dugwell program in West Bengal, India', Journal of Environmental Science and Health, Part A, 42: 1, 89 — 95

To link to this Article: DOI: 10.1080/10934520601015834

URL: http://dx.doi.org/10.1080/10934520601015834

Journal of Environmental Science and Health Part A (2007) **42**, 89–95

ISSN: 1093-4529 (Print); 1532-4117 (Online)
DOI: 10.1080/10934520601015834

Arsenic concentrations and bacterial contamination in a pilot shallow dugwell program in West Bengal, India

MEERA M. HIRA-SMITH,[1] YAN YUAN,[1] XAVIER SAVARIMUTHU,[2] JANE LIAW,[1] ALPANA HIRA,[3] CYNTHIA GREEN,[4] TIMIR HORE,[5] PROTAP CHAKRABORTY,[6] ONDINE S. VON EHRENSTEIN[1] and ALLAN H. SMITH[1]

[1]*School of Public Health, University of California, Berkeley, CA, USA*
[2]*Department of Environmental Science, St. Xavier's College, Kolkata, India*
[3]*Department of Geography, Shibpur Dinobundhu (Institution) College, Howrah, India*
[4]*Masters candidate, Environmental and Water Resources Engineering, University of Texas, Austin, Texas, USA*
[5]*C&H Environmental, Inc., Hackettstown, New Jersey, USA*
[6]*Former Director, Geological Survey of India, Kolkata, India*

Project Well has developed a pilot self-supporting community-based mitigation program to provide arsenic-safe water to the villagers of North 24 Parganas, West Bengal, India. Shallow concrete dugwells, less than 25 feet deep, that tap into an unconfined aquifer are constructed following stipulated guidelines. The design differs from the traditional dugwell in two major ways: (i) there is a layer of coarse sand in the annular space enveloping the outer wall of the concrete cylinder; and (ii) handpumps are used for water extraction to reduce the potential for bacterial contamination. Monitoring programs for arsenic and coliform bacteria in selected dugwells have been completed. In summer, when the water levels were low, the arsenic concentrations were measured. In 11 wells, measured over three years, the average water arsenic concentration was 29 μgL^{-1}. Two dugwells had high concentrations of arsenic (average 152 μgL^{-1} and 61 μgL^{-1}), but the remaining nine dugwells had an overall average of 11 μgL^{-1}. Seasonal variation was assessed in five wells with monthly measurements and there was a direct relationship between increases in arsenic concentrations and decreases in the volume of water in the dugwells in the dry summer season. To control bacterial contamination, sodium hypochlorite solution containing 5% chlorine was applied once a month. In 2005, fecal coliform was undetected in 65% (n = 13) of the dugwells but detected at high levels in 35% (n = 7) of the dugwells. The program clearly reduced exposure to arsenic, but we conclude that further study of increases in arsenic concentrations in the dry season are warranted, as well as assessment of ways to more effectively control bacterial contamination such as more frequent chlorination, perhaps with lower doses on each occasion.

Keywords: Surface water, Dugwells, Arsenic, Drinking water, Chlorination, Arsenic mitigation.

Introduction

Millions of people residing in the Ganga Brahmaputra Plain, which includes the states of Uttar Pradesh, Bihar and West Bengal in India, the Terai region of Nepal and most of Bangladesh, are drinking arsenic contaminated water. In adults, ingestion of arsenic causes cancers of the lung, bladder and skin, as well as noncancer cardiovascular, respiratory, reproductive, neurological, and dermal effects.[1]

Several arsenic mitigation programs have been introduced by governmental and non-governmental organizations[2] (NGOs) in India and Bangladesh to provide arsenic-safe water. Various types of community and domestic arsenic filters have been introduced in many districts of West Bengal and Bangladesh, but reports of their sustainability are unsatisfactory. As short-term alternative options, the following methods have been implemented: harvesting of rainwater as established by the NGO Barefoot College of Rajasthan;[3] use of pond sand filters and modified dugwells as implemented by the Dhaka Community Hospital in Bangladesh;[4] and shallow modified chlorinated dugwells installed by Project Well[5] (PW) in West Bengal, India. These interim solutions have the potential to be quickly implemented until long-term methods such as pipeline distribution of treated surface water or water from carefully constructed deep tubewells can be established. The pipeline system would require a considerable amount of time and capital to construct and maintain.

Address correspondence to Meera Hira-Smith, UC Berkeley School of Public Health, 140 Warren Hall, MC 8360, Berkeley, CA 94720, USA; E-mail: mmhsmith@berkeley.edu
Received June 20, 2006.

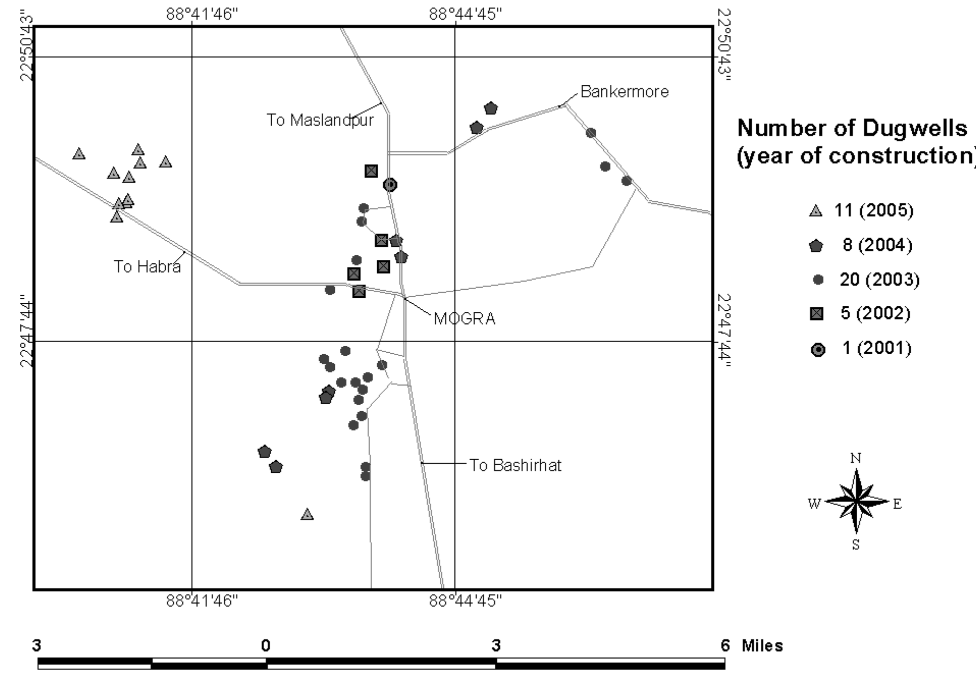

Fig. 1. Location map of 45 dugwells constructed (2001–2005) in North 24 Parganas, West Bengal, India.

Arsenic groundwater contamination and its effects on the people of North 24 Parganas have been discussed elsewhere in detail.[6] In 2001, Project Well introduced the first dugwell[7] in the district of North 24 Parganas. In 2002, five dugwells with slight changes in design were constructed in Simulpur and Kamdebkathi villages. One year later, 20 more dugwells were constructed in the villages, namely North and South Kamdebkathi, Kolsur, Chandalati and Chondipur. In 2004, 8 dugwells, and in 2005, an additional 11 dugwells, were constructed in Bamondanga, Ranidanga, Kolsur, Ranihati, Chandalati and Kharo villages. Figure 1 shows the location of all 45 dugwells. The georeferences of the area are Latitude: 22°45′56.62″ N to 22°50′11.76″ N and Longitude: 88°46′59.84″E to 88°40′47.53″E, covering an area of approximately 38 sq miles. The five dugwells that were included in the 2-year monitoring program are within an area of 0.74 sq miles.

Dugwell design and modifications

Dugwells, along with surface pond water, were a traditional source of water in this region before the introduction of tubewells. Though the general geology of the area is that of the young deltaic Plain, the geology of individual sites differs. During site selection, it was observed that the area was traversed by the river channel locally known as Padma, which over the years has built levees and swales. Later, settlements developed on the levees, farmlands and water bodies in the swales.

The design of these dugwells differs from traditional dugwells mainly in the 1-foot layer of coarse sand enveloping the outer wall of the concrete cylinder with the objective of reducing the entry of bacteria and assisting water recharge into the well. Nylon (mosquito) netting is used to cover the mouth of the well opening to prevent frogs, snakes, lizards, and insects from entering the well. In addition, a tin sheet is used to cover the well and enables padlocking of the well to prevent tampering. To reduce potential bacterial contamination, the water is extracted with a hand pump (Fig. 2) that is connected by an iron pipe to the dugwell. The hand pumps are the same as those used for tubewells, so villagers are already familiar with their use.

The average depth of these shallow, modified dugwells is 18 feet. The dugwells that were constructed in the program before 2004 were observed to have in-flow of material like sand and soil that continued throughout the year. The length of the fixed pipe was frequently readjusted, and dredging became mandatory in the dry summer months to increase the volume of water. Beginning in 2004, instead of fixed iron pipes, flexible rubber polyvinyl chloride (PVC) pipes were installed. The diameter of the PVC pipe is 1.5 inches. A plastic ball, five inches in diameter, is tied to the pipe for suspension so that the opening of the pipe remains about one foot below the water surface irrespective of the depth of water.

Initially, in 2001, potassium permanganate was used as a disinfectant, but since 2002, water has been chlorinated to control the growth of bacteria because it is easier to apply and is a common disinfectant. Theoline (trade name) is applied once a month to the wells. Theoline contains sodium hypochlorite (liquid bleach) that consists of 5%–10% available chlorine, 0.2% free alkali and water. Twenty-four ounces of Theoline can disinfect 100 gallons of water (USEPA standard).[8] A tabulated chart in the regional

Fig. 2. The dugwell # PW45KLS13 in the Kumro Kashipur area.

language of Bengali, containing the recommended dose of Theoline and the corresponding height of water in the well, is given to villagers. The height of water, which changes almost every month, is the difference between the total depth of water, DOW, and the depth to water, DTW. Each community-based group possesses a nylon rope to measure the height of water. The dugwell owners are advised to make two knots as they measure DOW and DTW and to take the rope to the Theoline distributing center where the correct amount of the Theoline is dispensed.

Materials and methods

Monitoring of arsenic concentrations in five dugwells constructed in 2002 was done from August 2002 to July 2003 and from December 2003 to November 2004. In addition, an annual monitoring program for 11 out of 34 dugwells was conducted during the summer months (April and May) in 2003, 2004, and 2005. Total and fecal coliform counts were measured in water samples from the dugwells constructed in June 2003 (one well), June 2004 (8 wells), and September 2005 (11 wells). Measurements of 13 heavy metals, including antimony, arsenic, beryllium, cadmium, chromium, copper, lead, mercury, nickel, selenium, silver, thallium and zinc, were also taken in two dugwells and fluoride measurements were taken in one dugwell.

Water samples were collected and sent to the laboratory of Dr. Dipankar Chakraborti at the School of Environmental Studies (SOES) at Jadavpur University in Kolkata where arsenic was measured using flow-injection hydride generation atomic absorption spectrometry (AAS).[9] The detection limit was 3 μgL^{-1}. In September 2005, the total coliform (TC) and fecal coliform (FC) counts of 20 dugwell samples were analyzed using the membrane filtration method. SM-9222B was used to detect TC and SM-9222D was used to detect FC. Samples were collected 30 days after the treatment with disinfectant, and prior to the next dose. To draw water from the dugwells, the attached tubewell was pumped 20 times before water was collected in labeled, pre-sterilized bottles. Water samples were collected in duplicate with codes assigned so that the laboratory could not identify the duplicates. At the beginning of 2004, three dugwells (ID#: PW6, PW17 and PW19) were selected for measuring the concentrations of 13 heavy metals. PW19 was selected because of a salty taste in the water and PW6 was selected because of increased arsenic levels during the two previous summers. Aqua ProTech laboratory in New Jersey, USA analyzed the samples using the SM3113-B method. Water samples were collected in 10 mL pre-sterilized bottles and transported from India to the laboratory in a styrofoam box packed with dry ice.

Results and discussion

Arsenic analysis

The annual average arsenic concentration in water samples from the five dugwells in 2002–2003 was 22.8 μgL^{-1}, and in 2003–2004 it was 26.3 μgL^{-1}. One dugwell, PW6, showed high levels of arsenic in the summer months. Discounting PW6 values, the annual averages were 13.0 μgL^{-1} and 18.0 μgL^{-1}, respectively. In West Bengal, the dry season starts in December with a few spells of showers and thunderstorms in March and April that are induced by locally formed low-pressure systems. The water column begins decreasing in December and arsenic concentrations start increasing in March until the onset of rain in June, when

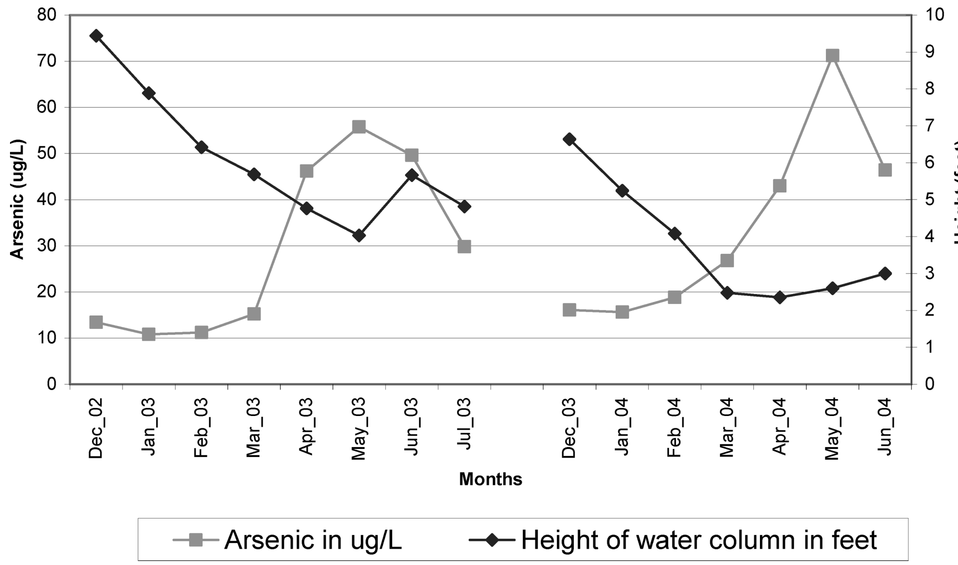

Fig. 3. Relationship between height of water column and levels of arsenic in the 5 dugwells (Dec 02 to July 03 and Dec 03 to June 04).

arsenic concentrations fall back down again (Fig. 3). The arsenic concentrations remained below 50 μgL^{-1} throughout the year in all but one dugwell.

From 2003 to 2005, the average summer arsenic concentration of 11 dugwells was 29 μgL^{-1}, including two wells with high concentrations. Nine (82%) dugwells contained arsenic levels average 11 μgL^{-1} and two (18%) dugwells contained arsenic levels $>$50 μgL^{-1} (average 99.2 μgL^{-1}) (Fig. 4).

Bacteriological analysis

Figure 5 shows the averages of duplicate measurements of total coliform (TC) and fecal coliform (FC) from 20 dugwells. TC was detected in all the sources except 2, PW10 and PW28. FC was undetected in 13 dugwells (65%), but the average FC counts for 7 dugwells in which FC was detected was 2614 counts/100 mL, a very high level. Dugwell users were advised not to use the water for drinking when any level of FC was detected. Dugwells with high counts of FC were classified as research and development wells and were subjected to a program involving weekly applications of Theoline for one month. Lime was used to reduce any organic odor; the organic smell decreased in all but one dugwell, and the water will be used for drinking only after another set of bacteriological and residual chlorine tests is taken of the wells that had high counts of bacteria.

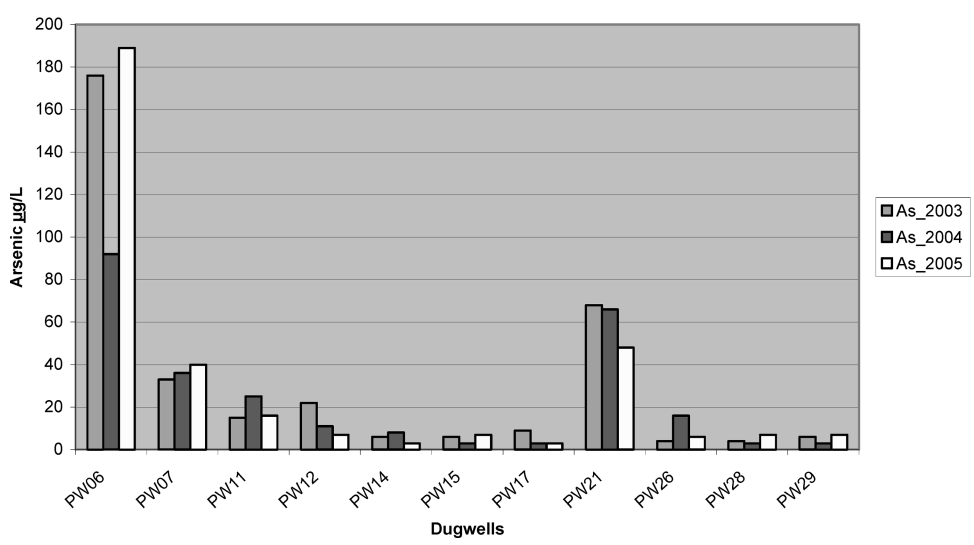

Fig. 4. Summer arsenic levels in μgL^{-1} of 11 dugwells of 3 consecutive years, 2003–2005.

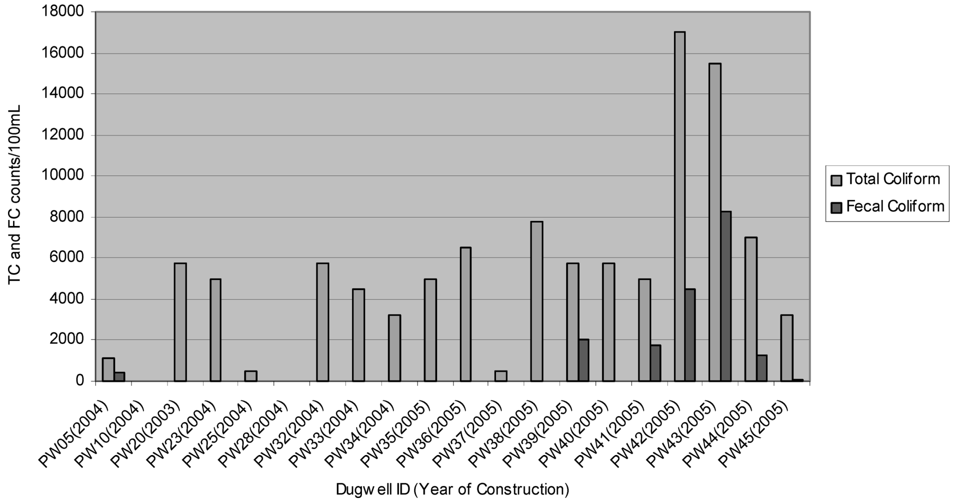

Fig. 5. The averages of duplicate measurements of total coliform and fecal coliform counts of 20 dugwells and the year of construction.

Consumers are visited monthly by field workers and asked about outbreaks of diarrhea and dysentery among users of each dugwell. There have been no such outbreaks linked to any particular dugwell water use over a period of four years.

Analysis of heavy metals

The 13 primary heavy metals (Table 1) were not present at detectable levels in both analyzed dugwells, (PW6 and PW19) except for mercury, which was at 44 μgL^{-1} (Bureau of Indian Standards, BIS, is 2 μgL^{-1}) in PW19. Water from PW19 was reanalyzed the following month and mercury was undetected, suggesting the previous detection may have been the result of contamination during local transportation and transfer of the sample. Fluoride was tested in only one well, PW17, and the measured level was 0.2 μgL^{-1} (BIS is 4 μgL^{-1}).

The arsenic concentrations in the dugwell water samples were generally below 50 μgL^{-1}, with an overall average of 29 μgL^{-1}. The dugwells replaced tubewells having average arsenic concentration in 2003 (measured in twenty tubewells) of 473 μgL^{-1}, and average concentration (in 17 tubewells) in 2004 of 140 μgL^{-1}. These tubewells were analyzed during the site-selection procedure prior to new dugwell construction. Thus, there has been a major reduction in arsenic exposure. Dugwells in Bangladesh and West Bengal have been analyzed and it was reported that 90% of 700 *traditional* dugwells contained arsenic levels <50 μgL^{-1} (average 15 μgL^{-1}).[10] However, seasonal variation in arsenic concentrations has not thus far been studied.

A report published by the British Geological Survey stated that three monitored traditional dugwells in

Table 1. Measurements of 13 heavy metals in PW-6, PW-19 and mercury and fluoride of PW17 and the dates of collection of samples.

Parameter	*BIS, Drinking Water Standard*	*PW-6 2/09/04*	*PW-19 2/09/04*	*PW-19 3/15/04*	*PW-17 3/15/04*
Antimony	0.006	U	U	NA	NA
Arsenic	0.01	0.030	U	U	U
Beryllium	0.004	U	U	NA	NA
Cadmium	0.005	U	U	NA	NA
Chromium (Total)	0.1	U	U	NA	NA
Copper	1.3	U	U	NA	NA
Lead	0.015	U	U	NA	NA
Mercury	0.002	U	0.0440	U	U
Nickel	NL	U	0.006	NA	NA
Selenium	0.05	U	U	NA	NA
Silver	0.1	U	U	NA	NA
Thallium	0.002	U	U	NA	NA
Zinc	5	U	0.59	NA	NA
Fluoride	4	NA	NA	NA	0.2

BIS-Bureau of Indian Standard, U—undetected, NA—not analyzed, NL—not listed.

Bangladesh had low levels of arsenic with slight temporal increases (no data given) that they considered negligible because the levels were within permissible limits stipulated in Bangladesh.[11] Arsenic concentrations in the monitored Project Well dugwells fluctuated over a period of three years, possibly related to the amount of rainfall, volume of water, and the depth of the dugwells. However, it was clearly observed that arsenic concentrations increase in the dry season along with the decrease in the volume of water (Fig. 4). Hence, in the future, we plan to monitor arsenic concentrations in dugwells each summer.

Conclusion

To combat diarrheal diseases caused by surface water, the practice of installing small-diameter tube wells, both shallow and deep, became common in West Bengal and the neighboring states and countries. Though the tubewells have since been found to contribute to serious arsenic health effects, morbidity due to surface water-borne diseases is still a public health issue affecting large populations. Every year during the monsoon season, many people living in the city of Kolkata[12] and in the rural districts of West Bengal[13,14] contract water-borne diseases such as diarrhea and various types of dysentery. In India, diarrhea is the major cause of death among children below the age of five.[15]

The factors that most affect bacterial contamination of drinking water in the home relate to personal hygiene practices. In one study, pathogenic bacteria were detected on feeding utensils, leftover food and water; 40% of mothers in the study with children below five years of age transmitted *E. coli* to their children by way of improper hand-washing practices.[16] So far, we have not detected any outbreaks of diarrhea due to bacterial contamination of dugwells. However, our findings suggest that careful monitoring is still required in order to improve the chlorination program. The reaction of chlorine with peat soil and the health effects of disinfectant by-products including trihalomethanes (THMs) and haloacetic acids (HAAs) are also a matter of concern;[17] hence, dugwells installed by Project Well were initially chlorinated only once a month. Project Well plans to assess the effects of more frequent chlorination, using lower concentrations on each occasion.

Acknowledgments

Thanks go to all the honorary members and advisors of Project Well and Aqua Welfare Society, with special thanks for the support of Dr. M. Hira, Kolkata. The fieldwork undertaken by Dennis Baroi (field supervisor), Ashutosh Biswas, Surojit Mondol and Farida Bibi are much appreciated. The project coordinator, Sekhar Pal, links the grassroots level work with the database to oversee the monitoring of water quality and the consumer history. Initially the fund was disbursed through Loka Kalyan Parishad, a local non-government organization (NGO) based in Kolkata, and currently it is being executed by the Aqua Welfare Society based in Kamdebkathi near Kolkata. The authors appreciate the help of gastroenterologist Prof. D. N. Guha-Mazumder, Kolkata, in preparing the questionnaire for the diarrhea surveillance program. Water analyses were performed at the laboratories SOES, Kolkata, India (arsenic), Envirocheck, Kolkata, India (bacteria) and Aqua Pro-Tech, New Jersey, USA (heavy metals). The funds for dugwell construction and first year of maintenance in 2005 were provided by the Blue Planet Run Foundation and Sanskriti, Maryland, USA. In 2004, Project Well raised the funds from private donors for dugwell construction and maintenance and for the research program, and in 2003, funds were provided by Rotary International and Danville Sycamore, California, USA, for the construction of 20 dugwells. Prior to 2003, Project Well was funded by Bay Area Prabasi, California, USA. Additional support was provided by NIH (5 P42 ES04705-18) and Fogarty International Research and Training Program in Environmental and Occupation Health (D43 TW-000-815-09). Dr. Xavier Savarimuthu, co-author, was a trainee in the Fogarty International Research and Training Program.

References

[1] National Academy of Sciences. Human health effects. In *NRC Report: Arsenic in drinking water*; National Academy Press: Washington DC, 2001 Update; 24–74.

[2] Robinson, A. Case study: Developing private sector supply chains to deliver rural water technology, arsenic mitigation in West Bengal and Bangladesh. ⟨http://www.wsp.org/publications/sa_arsenic.pdf⟩ Water and Sanitation Program South Asia 2000, Accessed November 25, 2005.

[3] Barefoot College, Rajasthan, India. Rain water harvesting. ⟨http://www.barefootcollege. org/html/water.htm⟨ Accessed August 2005.

[4] Dhaka Community Hospital. Drinking water supply through pipeline from dugwell. ⟨http://phys4.harvard.edu/%7Ewilson/arsenic/remediation/dugwells/DCH%20dugwell_Phase3_report.doc⟩ 2004, Accessed November 25, 2005.

[5] ProjectWell. ⟨http://projectwellusa.org⟩ 2004, Accessed June 19, 2006.

[6] Rahman, M.M.; Mandal, B.K.; Chowdhury, T.R.; Sengupta, M.K.; Chowdhury, U.K.; Lodh, D.; Chanda, C.R.; Basu, G.K.; Mukherjee, S.C.; Saha, K.C.; Chakraborti, D. Arsenic groundwater contamination and sufferings of people in North 24-Parganas, one of the nine arsenic affected districts of West Bengal, India. J. Environ. Sci. Health Pt. A **2003**, *A38* (1), 25–59.

[7] Smith, M.M.; Hore, T.; Chakraborty, P.; Chakraborty, D.K.; Savarimuthu, X.; Smith, A.H. A dugwell program to provide arsenic-safe water in West Bengal, India: preliminary results. J. Environ. Sci. Health Pt. A **2003**, *A38* (1), 289–299.

[8] USEPA. Drinking Water Regulations and Health Advisories. Chlorination Methods For Well Water. Scheduled D. *Methods For Disinfecting Water Wells*. October, 1996.

[9] Samanta, G.; Chowdhury, T.R.; Mandal, B.K.; Biswas, B.K.; Chowdhury, U.K.; Basu, G.K.; Chanda, C.R.; Lodh, D.; Chakraborti, D. Flow injection hydride generation absorption spectrometry for determination of arsenic in water and biological samples from arsenic-affected districts of West Bengal, India, and Bangladesh. Microchem. J. **1999**, *62*, 174–191.

[10] Chakraborti, D. Our experience of arsenic in dugwells. ⟨http://phys4.harvard.edu/%7Ewilson/arsenic/remediation/Dipankar Chakraborti_strategies.html#Dugwells⟩ 2005, Accessed March 1, 2006.

[11] Kinniburgh D.G.; Smedley, P.L., Eds. *Arsenic Contamination of Groundwater in Bangladesh*. Final Report, BGS Technical Report WC/00/19; British Geological Survey, Keyworth, U.K. 2001, Vol. 2, Chap. 10, 175–185.

[12] Dutta, S.; Dutta, P.; Matsushita, S.; Bhattacharya, S.K.; Yoshida, S. Shigella dysenteriae serotype 1, Kolkata, India. Emerg. Infect. Dis. **2003**, *9* (11), 1471–1474.

[13] Mondal, N.C.; Biswas, R.; Manna, A. Risk factors of diarrhoea among flood victims: a controlled epidemiological study. Ind. J. Pub. Health **2001**, *45* (4), 122–127.

[14] Biswas, R.; Pal, D.; Mukhopadhyay, S.P. A community based study on health impact of flood in a vulnerable district of West Bengal. Ind. J Publ. Health **1999**, *43* (2), 89–90.

[15] Banerjee, B.; Hazra, S.; Bandyopadhyay, D. Diarrhea management among under fives. Ind. Pediatr. **2004**, *41* (3), 255–260.

[16] Dutta, S.; Mondal, S.K.; Saha, M.R.; Sengupta, P.G.; Gupta, D.N.; Ghosh, S.; Sircar, B.K. Isolation of *Escherichia coli* to detect faecal contamination of infants and their mothers in West Bengal. J. Diarrhoeal Dis. Res. **1997**, *15* (3), 173–176.

[17] Fleck, J.A.; Bossio, D.A.; Fujii, R. Dissolved organic carbon and disinfection by-product precursor release from managed peat soils. J. Environ. Qual. **2004**, *33* (2), 465–475.