INTERNATIONAL PERSPECTIVES

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Health and Socioeconomic Effects of Groundwater Arsenic Contamination in Rural Bangladesh: New Evidence from Field Surveys

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Abstract

This report discusses the health and socioeconomic problems that have recently emerged in the Bangladesh countryside because of arsenic contamination of the groundwater. A survey found that men in rural households are generally found to be more susceptible to arsenicosis than women. The survey also indicated that villagers with lower annual income are more likely to experience arsenicosis. About 60 percent of the respondents indicated a willingness to pay up to a dollar of their monthly income for safe water. More than 70 percent of women were found to be willing to walk for five minutes to collect safe water. Awareness campaigns conducted over the last decade seem to have been effective for villagers. Overall, findings from the survey paint a picture of a gradually evolving social and health scenario in rural Bangladesh that health officials must heed to safeguard the public health of the rural public.

Introduction

Access to a safe water supply is one of the most important determinants of health and socioeconomic development (Cvjetanovic, 1986). Bangladesh, however, has always had a problem obtaining clean water. In the 1970s, when it was realized that the rural population of the country lacked access to adequate sanitation because of severe microbiological contamination of surface water, the government, supported by international donor agencies (i.e., World Bank, UNICEF), installed millions of tube wells to tap "better-quality" groundwater sources. In 1993, however, it was discovered that these tube wells, which provide drinking water in rural Bangladesh, are contaminated with geologically derived arsenic (British Geological Survey, 1998).

Incidences of elevated arsenic concentrations in groundwater have also been reported in many other countries, such as Argentina (Nicolli, Suriano, Peral, Ferpozzl, & Baleani, 1989), Mexico (Del Razo, Arellano, & Cebrain, 1990), India (Chatterjee et al., 1995), China and Vietnam (Berg et al., 2001), Romania (Sibbald, 2002), and Lao People's Democratic Republic (Ahmed, 2003). Arsenic contamination of groundwater is known to be a problem even in the United States (Sonderegger & Ohguchi, 1988, Twarakavi & Kaluarachchi, 2006). The case of Bangladesh stands out, however, and needs no renewed introduction. Estimates are that about 103 million people (80 percent of the Bangladesh rural population) depend on shallow wells that have been excavated at a depth of less than 150 m (Ahmed,2003), and that more than half of the Bangladesh population may be at risk from the high levels of arsenic in these groundwaters (Yu, Harvey, & Harvey, 2003). Since the contamination was discovered in 1993, numerous studies have steadily improved understanding of the contamination scenario (Biswas et al., 1998; Burgess, Burren, Perrin, & Ahmed, 2000; Mukherjee & Bhattacharya, 2002; Hossain & Sivakumar, 2006; Hossain, Hill, & Bagtzoglou, 2007; Hossain, Bagtzoglou, Nahar, & Hossain, 2006; van Geen et al., 2003; Harvey et al., 2002; Harvey et al., 2006; McArthur, Ravenscroft, Safiullah, & Thirwall, 2001; Nickson et al., 1998; Yu et al., 2003). While much is known about the extent of the arsenic contamination scenario and its probable causes (Harvey et al., 2002; van Geen et al., 2003), less is known about the health and socioeconomic implications. In this article, we present findings from our own field surveys of the rural countryside to assess the socioeconomic and health aspect of the arsenic problem. The motivation for this work was the belief that planners at the national level need to recognize the gradually evolving

TABLE 1

Socioeconomic Information from the Villages Surveyed[a]

Village (Division)[b]	Area (km²)	Total House-holds	Number of Tube Wells	Population Density (per km²)	Population	Male (%)	Female (%)	Poverty Incidence, by Division (%)	Literacy (%)		Arsenic Concentration in Tube Well Water (µg/L)
									Male	Female	
Rajarampur (Rajshahi)	2.5	1557	320	3313	8283	48.36	51.64	61.6	49.2	33.2	113
Ranihati (Rajshahi)	6.17	916	327	863	5235	50.38	49.62	61.6	31.7	22.5	920
Mianpur (Rajshahi)	2.08	236	109	845	1733	52.42	47.58	61.6	33	19.6	<50
Ochinto Nagar (Khulna)	2.05	353	130	713	1462	51.46	48.54	46.4	34.8	19.8	30
Pukuria (Dhaka)	2.3	396	121	894	2057	50.16	49.84	33.0	38.4	24	<50

[a] The authors collected these data in June 2005 from the NGOs working in the villages surveyed.
[b] *Source:* Bangladesh Bureau of Statistics (2001, 2002).

socioeconomic and health impact of arsenic contamination in order to make the long-term remediation and management efforts as effective as possible.

Findings from our field surveys may be interpreted and subsequently built upon by readers in various ways. For example, our survey results provide an objective framework for improving problem definition in questions such as *what social and health imbalances are expected to result from the arsenic problem and what are the options available for their mitigation? What are the anticipated broader effects on the rural and national economy of Bangladesh? How should national-level economic planning be revised and coordinated with health management efforts to synergize the remediation of the arsenic problem?*

Field Surveys for Data Collection

We began fieldwork in Bangladesh in January 2005. Detailed information was first gathered on the arsenic situation for the basic administrative unit, the village (or *gram*), from published reports of the Department of Public Health and Engineering (DPHE) and from meetings with nongovernmental organization (NGO) officials in Dhaka (Kinniburg & Smedley, 2001b). DPHE, which is responsible for water supply and sanitation in the rural areas of Bangladesh, has been implementing a nationwide project on the mitigation of arsenic "Bangladesh Arsenic Mitigation Water Supply Project" (BAMWSP) (see www.bamwsp.org). BAMWSP also maintains a database of test results from water samples taken from contaminated areas all over the country.

Given the constraints of field site accessibility and time, we chose five villages for field visits on the basis of the following criteria: 1) high arsenic contamination, 2) inadequate supply of safe drinking water, and 3) existence of ongoing arsenic mitigation projects. These villages were Rajarampur and Ranihati villages in Ranihati Union of Nawabganj Sadar Upazila (Chapai Nawabganj District, Rajshahi Division); Mianpur village in Charghat Union of Charghat Upazila (Rajshahi District, Rajshahi Division); Ochintanagar village in Padhakar Union of Jhenaidaha Sadar Upazila (Jhenaidaha District, Khulna Division); and Pukuria village in Ghior Upazila (Manikganj District, Dhaka Division).

For each village, detailed background information on hydrogeological makeup, arsenic contamination levels, arsenicosis patients, and relevant mitigation/intervention activities was collected from various organizations, local NGOs and local government departments. During the first visit, we held informal meetings and focus group discussions with local people in all five villages to include a wide sample of the population (e.g., sufferers, nonsufferers, NGO staff, village elders, community leaders, and beneficiaries). On the basis of the results from the initial visit, we narrowed to three the villages that were to be surveyed in depth. A second visit was made in June 2005 to carry out in-depth fieldwork in the villages of Ranihati, Rajarampur, and Mianpur. Next, a questionnaire survey was administered in these villages to a total of 65 households that had arsenic patients. Use of experienced research assistants from local NGOs, who were knowledgeable about the locality, facilitated our questionnaire surveys. The questionnaire, which is available online at http://iweb.tntech.edu/fhossain/papers/Questionnaire_Arsenic-Survey_2006.pdf, comprised 30 open-ended questions, which eventually led to long discussions with each respondent.

Survey Results

Table 1 shows that the surveyed villages have almost equal numbers of male and female residents. Population density in each village is about 850 per square kilometer, which is close to the national population density of 855 (Bangladesh Bureau of Statistics, 2001). The one exception is Rajarampur. The villages have low female literacy and a high incidence of poverty (Bangladesh Economic Review, 2005). Established reports and interviews of officials indicate that the upazilas of Nawabganj and Charghat are two of the worst affected regions; on average, more than 48 percent of tube wells are contaminated (British Geological Survey & Department of Public Health and Engineering, 2001).

All the respondents drank water from tube wells and used the same water for cooking.

TABLE 2

Household Population Statistics Obtained from Survey Questionnaire

Name of Village	Number of Affected Households	Population			Average Number of Household Members	Number of Tube Wells	Number of Contaminated Tube Wells[a]	Number of Patients	
		Total	Male	Female				M (%)[b]	F (%)[b]
Ranihati	35	163	99	64	4.7	35	35	43 (41)	32 (50)
Rajarampur	14	56	31	25	4.0	14	14	12 (39)	9 (36)
Mianpur	16	66	31	35	4.1	16	16	20 (65)	15 (43)
Total	65	285	161	124		75	75	75 (65)	56 (43)

[a] Contamination was indicated by an arsenic test with results exceeding 50 ppb.
[b] Indicates percentage within same-sex population.

These respondents have been living in these villages for more than 35 years. All respondents were aware of the arsenic problem in the groundwater. Nearly all of the respondents enjoyed the facility of having a water source (tube well) within their home arena. We surveyed 35, 14, and 16 households, respectively, in the villages of Ranihati, Rajarampur, and Mianpur; the total number of people surveyed was 285. The number of patients identified was 75, 21, and 35 in Ranihati, Rajarampur, and Mianpur, respectively, as shown in Table 2.

Table 2 shows that all the tube wells used by the households were contaminated with arsenic. The average number of members in a household was 4.7, 4.0, and 4.1 in Ranihati, Rajarampur, and Mianpur, respectively. Our survey showed that, on average, about 46 percent of the total of 285 household members were arsenic patients, 26 percent male, and 20 percent female. If one considers the ratio of patients to nonpatients within the same sex groups, the percentage of males affected by arsenic is also found to be higher than that of females (Table 2, last column), except in the village of Ranihati. We speculate that an explanation for this pattern may be found through analysis of urinary arsenic. A previous study by Watanabe and co-authors (2001) reported that males in rural Bangladeshi communities were more susceptible to chronic arsenic poisoning than females because of larger intake of drinking water. Generally speaking, our finding points towards the need for gender-based research on the arsenic-affected communities, which is currently absent in Bangladesh.

When Table 1 and Table 2 are analyzed together, our survey reveals an interesting feature. The number of affected households and the number of patients were higher in Ranihati than Rajarampur, even though the mean arsenic concentration in drinking water (920 μg/L) and the population density (3,313/km^2) were much higher in Rajarampur than the mean arsenic concentration (113 μg/L) and population density (863/km^2) in Ranihati. Although the number of members per household in Ranihati was about 15 percent higher and average annual income was 20 percent less than in Rajarampur, the average annual expenditure was found to be similar in both villages (Table 1). Since both the villages are in the same poverty incidence area of Bangladesh, it is reasonable to surmise that the household members in Ranihati probably receive a lesser share of nutrition in their daily diet (because of larger family size) than do those in Rajarampur. Consequently, our survey results seem to support the notion that better nutrition can provide the poor villagers with a level of protection against the adverse effects of arsenic exposure. Evidence in published literature suggests that the role of nutrition is important in determining methylation efficiency and toxicity of arsenic retained in the body. Yang and Blackwell (1961) studied nutritional factors in the Blackfoot endemic region of China (Province of Taiwan). Their results indicated that residents of this region consume a diet low in protein, in particular the amino acid methionine. With reference to our survey, however, the possibility that nutrition is playing a role in the level of arsenicosis among patients should be construed as speculation until a more detailed nutrition-based study is undertaken.

Our survey queried the households about the willingness of villagers to pay for safe drinking water. Table 3 shows the willingness of the respondents to pay per month for access to safe drinking water. More than 60 percent of households in each village were willing to pay up to Taka 50 (U.S. \$0.83) per month. We also surveyed the willingness of villagers to spend time collecting safe water. In Bangladesh, it is mainly the women who cook and collect water for cooking and drinking. Having to walk to obtain safe water means an extra load of work for them (Akmam & Higano, 2002). Our survey asked the female heads of household how much they were willing to walk to prepare safe water. The percentages of respondents willing to walk given distances (measured in minutes) is reported in Table 4. It was found that all female respondents in Rajarampur, 72 percent of those in Ranihati, and 91 percent of those in Mianpur were willing to walk. The percentage of women who were not willing to walk at all was the highest in Ranihati (27.41 percent). The majority of the respondents were willing to walk for five minutes, while the average time respondents were willing to walk was 3.88 minutes in Ranihati, 4.60 minutes in Rajarampur, and 3.74 minutes in Mianpur. This assessment seems to match results of an earlier survey carried out by Hoque and co-authors (2004), in which villagers indicated their preference for walking long distances daily to collect safe water over using treatment kits in their households. The survey results on the willingness to walk must, however, be interpreted carefully. Our findings do not necessarily mean that women are more inclined to travel for water collection. The willingness to walk appears to be driven by the limitations of some of the water treatment options available. Many villagers

TABLE 3

Percentages of Households Willing to Pay Monthly for Safe Water (Amounts in Taka)[a]

Village	0 Taka	0–50 Taka	50–100 Taka	100–200 Taka	>200 Taka
Ranihati	35.19%	61.21%	1.75%	1.85%	00.00%
Rajarampur	30.46%	22.74%	43.32%	3.48%	00.00%
Mianpur	37.12%	59.31%	3.57%	00.00%	00.00%

[a] 1 U.S. Dollar = 65 Taka in 2005

TABLE 4

Percentages of Female Heads of Households Willing to Walk (in Minutes)

Village	0 Minutes	0–5 Minutes	5–10 Minutes	10–15 Minutes	Average Minutes
Ranihati	27.41%	66.72%	3.31%	2.56%	3.88
Rajarampur	00.00%	96.23%	3.77%	00.00%	4.60
Mianpur	8.70%	76.70%	14.60%	00.00%	3.74

have not found treatment options socially very acceptable. For example, Hoque and co-authors found that villagers in Srinagar (close to the capital Dhaka) avoided using iron-filling-based water treatment filters that remove arsenic for the following reasons: 1) low flow rates, 2) high maintenance requirements, 3) operating risk (some villagers have reported getting hurt while recharging the filters), and 4) the addition of odor to water by filtration.

Finally, our current field survey identified a marked absence of discrimination and neglect in behavior toward arsenic victims. Generally speaking, this finding contradicts the norm, as it has been well known that, if disease appears anywhere in rural Bangladesh, there is a natural tendency for people of that area to avoid and ostracize the affected people. We attribute this positive development to the extensive awareness campaign carried out by the NGOs and several government projects.

Discussion

How to Deal with the Problem

From current literature, it appears that the actual causes of high arsenic concentration in the groundwater of Bangladesh have not yet been clearly pinpointed. Out of the few hypotheses initially proposed to explain the possible mechanism of arsenic release, the scientific community appears to have converged on two major variants: 1) the pyrite oxidation hypothesis (Kinniburg & Smedley, 2001a), which posits that oxidation of the arsenic mineral arsenopyrite (FeAsS), or pyrite, results in release of arsenic into groundwater, and 2) the oxy-hydroxide reduction hypothesis (Nickson et al., 1998), which posits that reduction of arsenic-rich iron-oxi-hydroxides leaches the arsenic that remains in an adsorbed state on its surface. In a recent e-mail survey of experts designed to identify the prevailing views on the possible mechanism of arsenic release in Bangladesh, 58 percent of respondents supported the oxy-hydroxide reduction hypothesis, 33 percent supported the pyrite oxidation hypothesis, and 75 percent believed that over-extraction of groundwater had some relationship with the contamination of arsenic in groundwater in Bangladesh (Akmam, 2002; Akmam & Higano, 2001). A recent modeling and sampling study led Harvey and co-authors to comment that "Although arsenic contaminated groundwater in Bangladesh is a serious health issue, little is known about the complex transient patterns of groundwater flow that flush solutes from aquifers and carry solutes into the subsurface" (Harvey et al., 2006, page 1 of Abstract). On the basis of a combined modeling-cum-sampling study, they report that the arsenic concentration level in the groundwater may increase or decrease in the future (Harvey et al., 2006, page 1 of Abstract).

The prevailing lack of a unified theory explaining the mobilization of arsenic in groundwater appears to be delaying the achievement of a long-term structural solution for policy planners in Bangladesh. In the meantime, an interim solution is needed for the rural public. While there are many localized solutions (such as switching to surface water, harvesting of rain water, water treatment, and switching to deep aquifers), none appears to work effectively for all of rural Bangladesh. To assess various options, Akmam (2002) developed a multi-objective mixed-integer mathematical model based on Pareto optimality. The three main objectives considered in the model were arsenic risk, cost for treatment, and the distance people have to walk to get safe water elsewhere. Model simulations for the village of Taranagar Village (Meherpur district) showed that the optimal option was dug wells (at depths <15 m) and use of a surface water filter. Akmam's study indicated that expensive and sophisticated treatment options are not always socially compatible with the lives of the rural public unless they are packaged locally to promote sustainability. The recent 2007 National Academy of Engineering Grainger Challenge Prize competition that sought innovative solutions for removing arsenic from drinking water in Bangladesh incorporated this consideration of sustainability (see http://www.nae.edu/nae/grainger.nsf?OpenDatabase). The criteria of the competition specifically stressed that the solution had to be "socially acceptable" with "low life-cycle cost."

We would like to make a clear call for policy planners in Bangladesh to heed this same need for "social acceptability" for any solution proposed for villagers. The SONO filter developed by the recipient of the Grainger Challenge Prize 2007 is one such point-of-use method for removing arsenic from drinking water that appears socially acceptable to villagers. In this filter, a top bucket is filled with locally available coarse river sand and a composite iron matrix (CIM). The sand filters coarse particles and imparts mechanical stability, while the CIM removes inorganic arsenic. The water then drains into a bucket below, where it again filters through coarse river sand, then wood charcoal to remove organics, and finally through fine river sand and wet brick chips to remove fine particles and stabilize water flow. About 30,000 such SONO filters have been manufactured, although much remains to be done to make this method into a widely available option for rural Bangladesh.

Conclusion

Our field survey of 65 rural households among five villages has indicated that men are generally more susceptible to arsenic in the drinking water than women. Findings also indicate that villagers with lower per capita annual income are more likely to incur arsenicosis. We speculated that the latter finding reflects probable intake of inadequate nutrition in the daily diet of the poorer villagers. The willingness among villagers to pay extra for safe water provision was found to be high (60 percent), although the amount they were willing to pay did not exceed a dollar out of their monthly income. In addition, more than 70 percent of women were found to be willing to walk for five minutes or less to collect safe water. We have discussed the range of options available for policy planners in Bangladesh, stressing in particular the need for social acceptability. Overall, findings from our survey paint a gradually evolving social and health scenario that should be heeded by policy planners if they are to restore the public health of rural Bangladesh.

The main challenges that are ahead for Bangladesh in managing the contaminated groundwater are now 1) locating the sources of the poisoning and closing them to avoid further release of arsenic via the routes of food, soil, and water; 2) creation of mass awareness about the danger of drinking arsenic-contaminated water; 3) provision of arsenic-free, bacteriologically and chemically safe alternative sources of drinking water to the vast majority of the population; and 4) diagnosing all arsenicosis patients and providing effective management of their condition. We strongly believe, however, that mitigation of arsenic should be executed in ways that suit local conditions and requirements with cognizance taken of the health and socioeconomic impacts that are already in effect. Thus, the local community should be fully involved in the planning and development of the water supply system; whether the system is filter-based, uses surface water, harvests rainwater, or takes some other approach, all concerned people should partake in managerial and financial responsibilities. This involvement will satisfy the critical need for social compatibility. The government must cooperate with academic as well as research institutes to assess the causes and impact of arsenic poisoning and take up remedial measures whenever and wherever necessary. Hence, more field surveys eliciting the villagers' response to various facets of health and socioeconomic issues need to be conducted to formulate a long-term community-based management strategy.

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