EcoHealth 7, 114–126, 2010
DOI: 10.1007/s10393-010-0309-y

ECOHEALTH

Original Contribution

Ecosystem Perspective of Groundwater Arsenic Contamination in India and Relevance in Policy

Atanu Sarkar

School of Environmental Studies, Queen's University, Room No 3134, Biosciences Complex, Kingston, ON K7L 3N6, Canada

Abstract: Millions of people living in India are at risk by consuming arsenic contaminated groundwater. Several technological solutions have failed to address the problem due to segmental approaches, resulting in human suffering for a period of three decades. The article is based on an analysis of arsenic-related health problems from an ecosystem perspective through a primary survey conducted in five arsenic affected villages in the state of West Bengal and review of existing research and policy documents. Although modern agricultural practices and drinking water policies have resulted in arsenic contamination of groundwater, current mitigation policy is essentially confined to biomedical approaches, which includes potable water supply and medical care. The study also shows that existing disparity, difficulty in coping, inaccessibility to health service and potable water supply and lack of participation in decision making have resulted in more suffering among the poor. On the other hand, spreading of arsenic contamination in the ecosystem remains unabated. Foods grown in the affected area have emerged as additional sources of exposure to humans. There is lack of evidence of any perceivable benefits due to sustainable agriculture, as present nature of agriculture practice is essentially driven by crop yield only. Further research is needed to generate credible evidence of alternative agriculture paradigms that may eventually reduce body burden of arsenic through reduced dependency on groundwater.

Keywords: arsenic, ecosystem, equity, groundwater, agriculture

INTRODUCTION

The first chronic arsenicosis[1] case in West Bengal was detected in 1982, followed by cases in four other Indian states and neighboring Bangladesh (Fig. 1). It is now recognized that millions of people from India have been endangered by the prospect of consuming water contaminated with arsenic at levels greater than the guideline value of acceptable level set by the World Health Organization (WHO) (10 μg/liter); more than 95% of them live in West Bengal (SOES, 2010). Chronic exposure to arsenic increases the risk for noncancerous skin lesions such as pigmentation changes and keratosis and diseases of the liver, lungs, nervous system, cardiovascular system, as well as cancers of the skin, lung, and bladder (Smith et al., 1992). Several studies have suggested a strong association between poor nutritional status and dietary intake (protein and micronutrients) with clinical manifestations of chronic arsenicosis. The study explained that the nutrition deficiency might result in slow metabolism, less detoxification in the

Published online: April 24, 2010

Correspondence to: Atanu Sarkar, e-mail: 7as52@queensu.ca; contactatanu@yahoo.co.in

[1]Disease with single or multiple symptoms of chronic arsenic exposure.

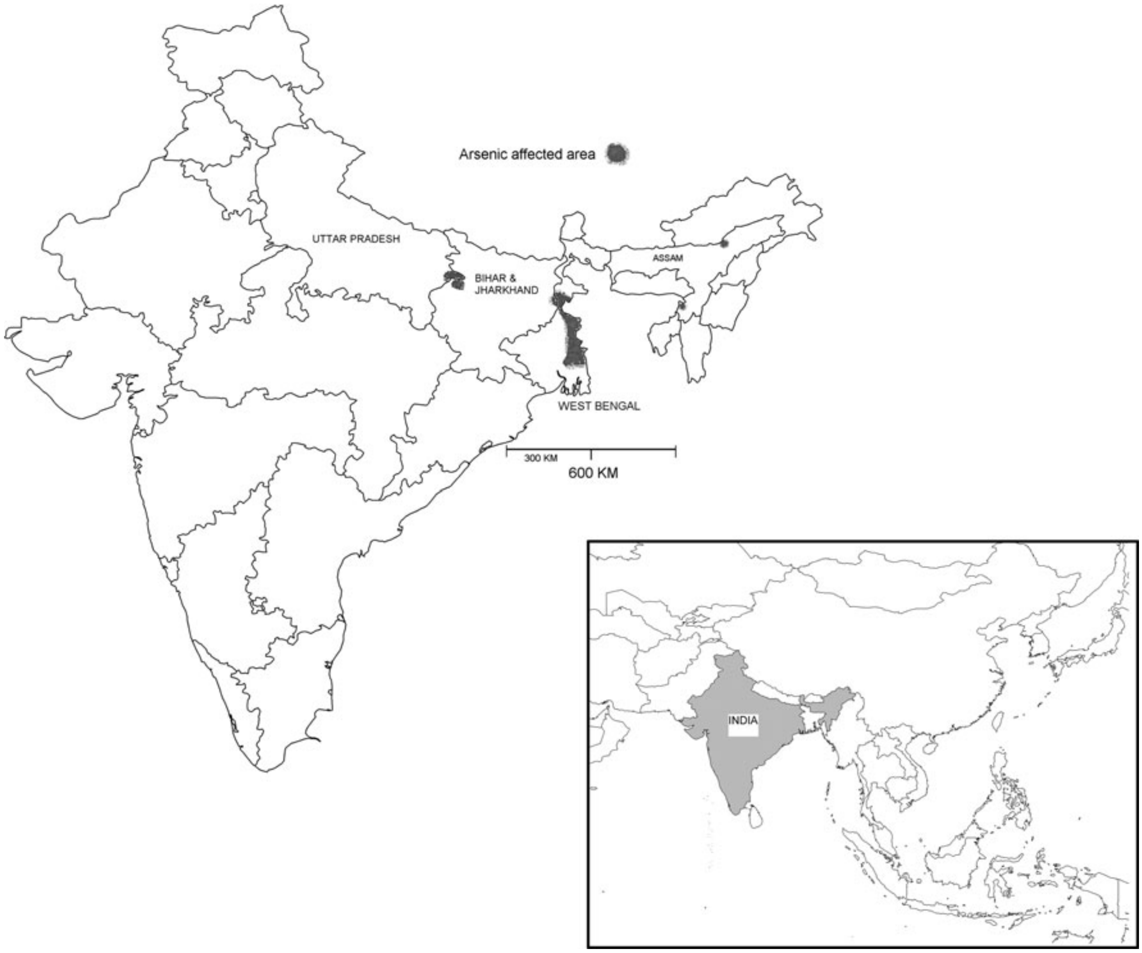

Figure 1. Groundwater arsenic contamination in India (adapted from SOES website (http://www.soesju.org/arsenic/arsenicContents.htm?f=health_effect.html) and south and southeast Asia (inset).

liver and impaired urinary elimination of arsenic. Thus, with increased body burden of arsenic, the clinical manifestations turn from milder to moderate and eventually to a severe variety (Haque et al., 2003; Rahman et al., 2001; Mitra et al., 2004). There is no specific medical treatment for these arsenic-related diseases, except using chelating agents to reduce the body burden by enhancing the elimination of arsenic through urine and salicylic acid ointments to provide temporary relief from keratosis.

The West Bengal alluvial plain is composed of three interconnected aquifer systems: the shallowest aquifer (extending up to 12–15 meters below the surface), the intermediate aquifer (35–46 meters), and the lower aquifer (70–150 meters). All aquifers are reported to be enriched in arsenic-containing minerals in varied concentrations (Stüben et al., 2003). In the affected areas, the aquifer sediments are capped by a layer of clay or silt (of variable thickness), which has effectively restricted entry of arsenic into the surface water (Smedley and Kinniburgh, 2002). However, human exposure has begun, through the tapping of groundwater sources after the introduction of domestic hand pumps and irrigation wells (Nickson et al., 2000).

This author argues that there is a need for a framework of information gathering that simultaneously reflects ecological, socioeconomic, cultural, and human health aspects while taking into account the interrelationships among these components to tackle groundwater arsenic contamination and health consequences. Ecosystem approaches to human health are designed to improve overall community health by focusing on both the social and ecological interactions in the analysis of health determinants and responses to health problems (Rapport and Singh, 2006). Furthermore, the ecosystem approach framework identifies both human activities that place stress on the environment and the impacts that changes in the environment have on human well-being. The ecology and transmission of most diseases are closely related to environmental resource management, social interaction and behavioral patterns and their persistence is largely rooted in social inequity, with poverty being the major impediment to their control and elimination (Noronha, 2004; Hartigan, 1999). The ecosystem and health framework includes three core elements: transdisciplinary; social justice and equity; and stakeholder participation. All three are essential to understand the social and ecological interactions that lead to disease, as well as to arrive at feasible ways to prevent transmission and improve health (Lebel, 2004). Furthermore, to evaluate the burden of disease due to environmental factors, priority setting and decision making, the application of an ecosystem and health framework can be very helpful (WHO, 2005). To develop an ecosystem perspective of arsenic contamination of groundwater, the present study has explored (1) causal pathways to human arsenic exposure, (2) assessment of vulnerability and equity, (3) current stakeholders in the mitigation program and challenges to converge the actions, and (4) a socially robust solution that integrates the knowledge of wide range of causal relations and adopts the common language.

Materials and Methods

The study was based on two phases of field visits to the arsenic-affected villages (microlevel analysis) and a review of research papers and government documents (macrolevel analysis).

Study Area

The first phase was performed in 1998–2004 in Domkol (an administrative block or county) of Murshidabad—one of the worst affected districts of West Bengal (Fig. 2). Five severely affected villages, which were earlier extensively surveyed by government and international agencies, were selected for the study. The arsenic level of all water sources and people's response to arsenic contamination were the most important components of this study. The second phase of the field study was conducted in 2005–2006, as a follow-up in the same villages to assess changes in human adaptation, vulnerability and policies.

Data Sources

In the first phase of the study, the entire population living in the five villages was screened for the presence of arsenic-related skin manifestations—the earliest clinical symptoms of chronic arsenicosis (Guha Mazumder et al., 1998). During the screening process, assessment of socioeconomic status and arsenic exposure (any history of intake of arsenic contaminated water on regular basis in past year) also was performed. After identification of chronic arsenicosis cases, in-depth examinations were conducted to determine the magnitude of arsenic exposure, nutritional history, and coping strategies. A number of focus group and informal discussions were conducted to obtain additional qualitative data from the study villages. Administrative officials of the local government (or *panchayat*[2]) from the villages and the block, with technical experts (health, irrigation, and agriculture) also from the block and officials from the district headquarters were interviewed to obtain information regarding governance, current mitigation strategies and related issues, as well as alternative development paradigms. In the second phase, information was gathered by a walk-through survey, as well as focus groups and informal discussions with the villagers and local administrative officials.

Methods

During first phase of the study, average arsenic levels in drinking water sources were measured for persons diagnosed with chronic arsenicosis. Water consumption patterns in the villages were very complex, because people drink water from multiple sources (including domestic sources and irrigation wells) on a regular basis. Therefore, to assess the average arsenic concentration in drinking water for each individual, average arsenic concentration (μg/L) from daily consumed water (from multiple sources) was measured.[3] Reports of groundwater arsenic levels were collected from the Public Health Engineering Department (PHED) of Murshidabad and the School of Environmental Studies (SOES), from Jadavpur University, Kolkata. Average daily intake of water from each source during a 1-year period and approximate duration (in days) of intake from each source/s were estimated by discussing with each respondent.

[2]The panchayat system as a form of local self-government has been embodied in the constitution of India. The experience of West Bengal under the panchayat system stands in sharp contrast to the other states in India and together with land reform it has been credited for playing an important role in the impressive economic turnaround of the state since the mid 1980s (Ghatak and Ghatak, 2002).

[3]Majority of the scientific research showing dose–response relationships takes into account the arsenic level of single principal source only and disregards proportional consumptions from multiple sources.

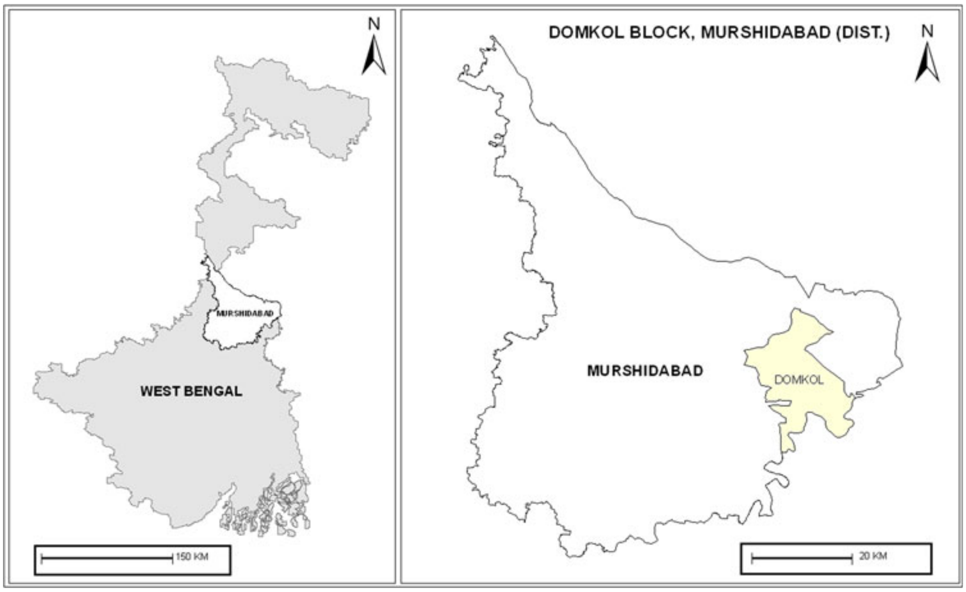

Figure 2. West Bengal, Murshidabad district, and Domkol block/county.

The average daily arsenic intake (µg/L/day) was measured as:

$$\text{Arsenic exposure}(\mu g) = \left(\sum A_n.L_n.D_n / \sum L_n.D_n\right)$$

A arsenic concentration (µg/L) of a particular source, *L* quantity of water of respective source (L/day), *D* duration (days) of water intake from respective source.

Additional exposure through food occurred; however, there was little scope to measure arsenic from food samples (cooked with contaminated water and crops grown in the lands irrigated by arsenic contaminated water).

The severity of skin manifestations of chronic arsenicosis was categorized as mild, moderate, and severe (Guha Mazumder et al., 1998). Socioeconomic status (SES) categories were constructed on the basis of a participatory assessment to reflect the local context.[4] All households were categorized into three SES categories: low (up to subsistence level), middle (relatively comfortable), and high (affluent).

The nutritional status of individuals was assessed by measuring the body mass index (BMI = weight (kg)/{height (m)}^{2}). BMI within the range of 20–25 is considered normal, whereas 18.5–20 and <18.5 are defined as low-normal and low, respectively (Asthana et al., 1998).

Results

Groundwater Use in Agriculture

Use of groundwater in irrigation began in the early 1970s and intensified in the early 1980s when farmers began cultivation of paddy in the dry winter season (known as *Boro* rice) in addition to the traditional monsoon season crop. In most cases, irrigation came from wells that sourced water from shallow and intermediate aquifers. Until 2006, there had been 17 irrigation wells being regularly used during the summer and winter seasons. In the rainy season, less groundwater had been used in irrigation; however, it was necessary for farmers to run groundwater pumps if the summer extended for a longer period. Due to lack of maintenance and regulation, the traditional irrigation systems, drawing from lakes, canals, and large ponds lost their water-carrying capacity due to silting, and hence could not meet the high water demand, particularly during the dry season. In several places, the local people drained water from former lakes to cultivate in the dry lake bed. The study identified 13 irrigation wells containing arsenic with concentrations ranging from 100 µg/L to 600 µg/L. The farmers, who spent prolonged periods working in the fields, often drank arsenic-contaminated water from irrigation wells, despite many of them having access to arsenic-safe

[4]In the study villages, measurement of socioeconomic status, based on conventional system, such as per capita income or ownership of household amenities or calorie intake, was found to be unrealistic. Rather people's perception of economic status was considered more feasible and contextually appropriate. Before the first phase of field survey, a pilot study was conducted in the study areas, which asked about their concept of subsistence level requirements and indicators of what was relatively comfortable and affluence. Furthermore, they were asked about nature and amount of household property required to maintain various levels of socioeconomic status. Because it is an essentially agrarian society, people responded in terms of landholding and assets, such as livestock and fruit trees.

domestic sources. The farmers indicated that carrying water bottles or any other containers from their homes was inconvenient and water became hot quickly.

Domestic Water Use

The study showed that approximately 90% of the rural population was dependent on groundwater for domestic consumption, including drinking and cooking, and 69% of these sources were contaminated with arsenic at levels greater than 10 μg/L. According to the village elders and health workers, since the 1970s, consumption of groundwater was extensively promoted by the government to combat water-borne infectious diseases from dug wells and ponds. Since the early 1970s until 2006, the total number of hand pumps had increased from almost nil to 76. Apart from drinking and cooking, groundwater also had been used to feed cattle and for irrigation of the kitchen garden. During the first phase of the field visit, it was found that the villagers accepted the hand pumps as the only sources of potable water and simultaneously had almost abandoned the ponds for domestic use, only using them for washing clothes and utensils, as well as for bathing. Most of the old dug wells had been filled up with earth or household waste.

Arsenic Levels in Water and Manifestation

A total of 9,427 people were screened; 7,678 had been exposed to arsenic from drinking water on a regular basis and 410 exhibited clinical signs (melanosis and leucomelanosis) of chronic arsenicosis. Detailed water intake of 410 cases indicated that the average arsenic levels in consumed water ranged from 10 μg/L per day to 600 μg/L per day. Table 1 illustrates the severity of clinical manifestation, which increased with higher arsenic levels (Chi-square test, $P < 0.03$).

Socioeconomic Status

The study villages were mostly (76%) inhabited by low SES, followed by middle (18%) and high (6%) SES categories. Table 2 shows that the prevalence rate of chronic arsenicosis was highest (6.3%) among the low SES, followed by middle (2.5%) and high (2.2%) SES. Of 22 deaths reported during the first phase of the study, 21 were from low SES and 1 from the middle SES.

Table 1. Severity of chronic arsenicosis and average arsenic level in daily consumed water

	Severity of manifestation			
	Mild (%)	Moderate (%)	Severe (%)	Total (%)
Arsenic level (μg/L/day)				
10–50	34 (64.2)	13 (24.5)	6 (11.3)	53 (100)
50–200	117 (50.6)	78 (33.8)	36 (15.6)	231 (100)
200–400	45 (54.9)	32 (39)	5 (6.1)	82 (100)
400–600	15 (34.1)	23 (52.3)	6 (13.6)	44 (100)
Total	211	146	53	410

Table 2. Prevalence rate of chronic arsenicosis and socio economic status

	SES			
	Low	Middle	High	Total
Exposed population	5808	1278	592	7678
Chronic arsenicosis cases	365	32	13	410
Prevalence rate (%)	6.3	2.5	2.2	5.4

Table 3 illustrates the association between SES and average arsenic level in daily consumed water, severity of manifestation of chronic arsenicosis, and age of the chronic arsenicosis cases. Arsenic level and severity of manifestation were associated with SES (Chi-square test, $P = 0.005$ and 0.008 respectively). The explanation for higher chronic arsenicosis among the young population with the low SES could be early exposure and/or associated factors, such as malnutrition. The research showed that the poor people generally started agricultural activities at an early age and were exposed to arsenic from irrigation wells. More severe forms of manifestation among the low SES population can be explained by the high arsenic exposures among them. However, the relationship between high exposure of arsenic and low SES was more complex. Occupation played an important role; for instance, agricultural laborers, who belonged to the low SES category, spent longer hours working in fields and more frequently drank water from arsenic-polluted irrigation wells. Landed rich farmers only occasionally visited the field to supervise the activities of the agricultural laborers; furthermore, many of them could afford to shift to potable water sources, such as using

Table 3. Average arsenic level in daily consumed water, severity of manifestation and age of chronic arsenicosis cases and socio economic status

	SES			
	Low (%)	Middle (%)	High (%)	Total
Arsenic level (μg/L/day)				
1050	41 (11.2)	6 (18.7)	6 (46.1)	53
50–200	208 (56.9)	19 (59.4)	4 (30.8)	231
200–400	73 (20)	7 (21.9)	2 (15.4)	82
400–600	43 (11.9)	0 (0)	1 (7.7)	44
($P = 0.005$)				
Severity of manifestation				
Mild	178 (48.8)	21 (65.5)	12 (92.3)	211
Moderate	135 (37)	10 (31.2)	1 (7.7)	146
Severe	52 (14.2)	1 (3.1)	0 (0)	53
($P = 0.008$)				
Total	365 (100)	32 (100)	13 (100)	410
95% confidence interval of age	20.4–28.1	28.2–39.8	36.3–48.9	
Range: 8–73 years				

Table 4. Average arsenic level in daily consumed water (μg/L/day) and occupation

	Arsenic level				
	10–50 (%)	50–200 (%)	200–400 (%)	400–600 (%)	Total (%)
Occupation					
Agricultural laborer	13 (7.2)	104 (57.4)	36 (19.9)	28 (15.5)	181 (100)
Household activity[a]	17 (13.2)	76 (58.9)	23 (17.81)	13 (10.1)	129 (100)
Student[b]	6 (31.2)	10 (52.6)	2 (10.5)	1 (5.3)	19 (100)
Landed farmer	3 (16.7)	10 (55.5)	3 (16.7)	2 (11.1)	18 (100)
Other[c]	14 (22.2)	31 (49.2)	18 (28.6)	0	63 (100)
Total	53	231	82	44	410

[a]Married and unmarried women and also young girls who quit school to assist mothers/elder sisters in household activities.
[b]Mainly students but occasionally helped in household working or farming and other occupational activities. Students who quit schools and joined farm activities or other household occupations were included in respective occupation.
[c]Including milkman, artisan, barber, service, business, etc.

arsenic filters, or obtaining water from their own newly sunk dug wells[5] (Table 4).

Agricultural laborers were found to be the most vulnerable followed by women involved in household activities. Women are generally not permitted to work outside the home due to the conservative nature of the society and thus had been exposed to arsenic exclusively from domestic sources.

[5]SOES conducted a study in the same county and found the arsenic level in the dug well water (~10 m depth) within safe levels, whereas the closest hand pumps, which drew water from the deeper aquifers (>15 m depth) were highly contaminated by arsenic. http://www.sos-arsenic.net/english/dugwell/dugwell3.html. Accessed February 2010.

Nutrition

Malnourished persons exhibited more severe forms of clinical manifestation of chronic arsenicosis and the association between nutritional status and severity of clinical symptoms was statistically significant (Chi-square test, $P < 0.001$) with BMI (Table 5). Not surprisingly, BMI was found to be significantly correlated with SES (Chi-square test, $P < 0.005$). In rural West Bengal, a combination of cereals (primarily rice and wheat) and various pulses had made up a traditional staple diet, one that provided a balanced combination of carbohydrate and protein. In the

Table 5. Severity of manifestation and body mass index

	Severity of manifestation			
	Mild (%)	Moderate (%)	Severe (%)	Total (%)
BMI[a]				
Low	19 (14.1)	76 (56.3)	40 (29.6)	135 (100)
Low Normal	63 (54.3)	44 (37.9)	9 (7.8)	116 (100)
Normal	95 (87.9)	11 (10.2)	2 (1.9)	108 (100)
Total	177	131	51	359*

[a]Body mass index is applicable to persons older than aged 14 years. Therefore, 48 persons (of 410) who were younger than 14 years with three overweight persons were removed and the rest of the 359 were considered for analysis.

Table 6. Food intake and socioeconomic status

SES	Cereal Mean ± SD	Pulse Mean ± SD
Low	14.26 ± 1.5	0.63 ± 0.23
Middle	15.35 ± 2.1	1.26 ± 0.16
High	15.94 ± 2.2	1.31 ± 0.29

SES socioeconomic status.

study villages, however, the average intake of staple food (kg/adult/month) was less among low SES; this was particularly true for pulses because they were more expensive items (Table 6). The mean pulse and cereal intakes of adults of high SES were 2.08 and 1.11 times greater than those of low SES categories respectively.

Locally grown fruits, vegetables, and fish were the only available sources of additional nutrition for the villagers. However, improved transport facilities and a high demand in nearby cities had resulted in the transport of almost all major products, eventually leading to a high price in the local rural market. In the second phase of the study, the situation was found to have further worsened as state-supported farmers' cooperative societies began to facilitate the farmers in sending local products outside the state of West Bengal, with the result being the reduction in their availability to the local population.

Gender

Of the total male and female populations, 89.2% and 66.1% had been exposed, respectively. A total of 272 male and 138 female chronic arsenicosis cases were identified with

Table 7. Average arsenic level in daily consumed water and severity of manifestation and gender

	Male (%)	Female (%)
Arsenic level (μg/L/day)		
10–50	33 (12.1)	20 (14.5)
50–200	152 (55.9)	79 (56.4)
200–400	57 (20.9)	25 (20)
400–600	30 (11.1)	14 (10.7)
Severity of manifestation		
Mild	108 (39.7)	103 (74.6)
Moderate	115 (42.3)	31 (22.5)
Severe	49 (18)	4 (2.9)
Total	272 (100)	138 (100)

prevalence rates of 6.01% and 4.37%, respectively. Males had slightly higher levels of arsenic in their daily water consumption; moreover, they also had a higher proportion of severe forms of manifestation (Table 7). Of 22 deaths, 18 were reported to be men.

Due to the link between arsenic exposure and occupation, men had higher exposure rates, using multiple sources and higher average water intake; particularly those who worked in the fields. During summer and during cultivation periods, men drank more than half of their daily water intake from irrigation pumps and, hence, the quantity of arsenic consumed was presumed to be much higher than women. Marriage was found to be an important reason for the gender differential in arsenic exposure. As arsenic distribution in the aquifers was scattered, several households even in the affected areas remained safe. There were several married women whose parental homes were arsenic-safe and they were exposed only after marriage, which led to shorter duration of exposure than their husbands.

Health Service

During the period of the first phase of study, proper medical care facilities were available only in Kolkata—the state capital (250 km from the study villages). However, there was an attempt to decentralize medical care by extending it to primary health centers—an initiative that was witnessed during the second phase. Despite this, a lack of doctors and an erratic supply of drugs resulted in continued dependency on Kolkata. Of 11 cases who sought treatment from Kolkata, 8 were from middle and high SES. Usually the poor villagers visited local government doctors or untrained health workers for palliative care. Gender disparity regarding treatment-seeking was evidenced. Although 97% of men sought treatment from local doctors compared with 88% of women, only men traveled to Kolkata for proper treatment. Long-term benefits of the medical care had been debatable as several patients complained of recurrence of symptoms after completion of treatment due to reexposure to arsenic-contaminated water after returning from hospitals.

Arsenic Control Strategy

During the period of the first phase of study, the mitigation strategy was found to be limited to the promotion of dug wells and sinking hand pumps to deeper, arsenic-safe layers. After the identification of a few arsenic-safe public hand pumps, the local public health authority advised the villagers to shift to these alternative sources as well. People from high SES had greater access to information and could afford to opt for alternative arsenic-safe sources of water for domestic use, such as new hygienic dug wells, sinking new hand pumps to extract water from deeper arsenic-safe aquifers, rainwater harvesting, and arsenic filters.

Conventional dug wells had a higher chance of bacteriological contamination due to percolation of polluted surface water from the surroundings. However, the newer version of dug wells were relatively safe as concrete rings were used to prevent percolation of contaminated water from upper parts of the subsurface layer and concrete sealing of the well top prevented further contamination (Rahman et al., 2010). It is worth noting that regular chlorination could ensure more protection from water-borne diseases. In fact, there had been an initiative to promote dug wells in another arsenic-contaminated district of West Bengal. This initiative encountered the problem of microbial contamination in its initial phase. Later, the problem had been resolved after improving the dug well design, construction and management, and involving the community through outreach programs (Project well (PW), 2009a, b, 2006; Smith et al., 2003). The author had an opportunity to visit the project area in 2006 and noticed that the acceptance of dug wells and the maintenance of water quality were dependant on social mobilization and community motivation to participate in collective actions. The arsenic filters were mostly of two types: domestic (to serve an individual household), and community-based (fitted with the hand pumps). The domestic filters were based on charcoal or alum and mainly provided by some local organizations. The community-based filters were based on adsorption, coprecipitation, and ion-exchange techniques and were provided by the PHED.

All interventions were believed to be beneficial to the community in terms of supply of arsenic-safe water and improvement of symptoms. However, the community, local authorities, and technical experts have expressed several shortcomings related to the existing mitigation strategies.

Arsenic filters

- Frequent breakdown and poor maintenance
- Lack of quality check and suboptimal filtration efficiency
- Management of highly toxic sludge, which is currently discarded in open fields, thus causing serious ecological hazards by contaminating soil and surface water

Dug Well

- Objectionable chlorine odor (as a result disinfection measures)
- Lack of community ownership resulting in poor maintenance (chlorination)
- Risk of water-borne diseases due to poor maintenance

Rainwater Harvesting

- Poor surface runoff due to the materials (straw) used to build roof (particularly poor households)
- Lack of storage facility for rest of the year as rainy season lasts for 3 to 4 months (although average annual precipitation of 1200–1600 mm is sufficient for household need)

Medical Care

- Erratic supply of medicine and nonavailability of health professionals
- Recurrence of symptoms after completion of treatment due to reexposure to arsenic

Due to lack of coordination and poor communication between PHED and health departments, local hot spots (i.e., cluster of arsenic-contaminated hand pumps) could not be identified and hence the subsequent actions, such as surveillance of cases and community awareness, could not take place. There also was a lack of community participation in the planning process, implementation, monitoring, and evaluation; for instance, several dug wells were sunk (by the PHED) adjacent to the swampy land covered with water hyacinths and because of the poor water quality, villagers have refused to use them (malodorous). Thus, several policies, which had developed at the central and federal level, could not garner community support and eventually failed to yield the desired result.

Macro Perspective of Development Policy

The present study was designed to examine this environmental health catastrophe in a more integrated way from an ecosystem perspective. Based on this perspective, a conceptual framework for human arsenic exposure pathways has been constructed (Fig. 3), which was derived from a review of macro level (state) data, addressing agriculture development, natural resource management, food contamination, food security, health services, and governance (described below).

To increase food production, the West Bengal government took a number of measures, including irrigation, intensive paddy cultivation, increased cropping frequency, and land development (more utilization of land for agriculture purpose). Paddy cultivation was given top priority by the state because rice had been the staple food in the region and farmers were familiar with its cultivation (Rawal and Swaminathan, 1998). The total area cultivated for rice production had increased from 4 million hectares in 1951–1956 to 6.1 million hectares in 2000. Paddy cultivation required very large amounts of water compared with other crops. Moreover, promotion of *Boro* rice (grown in dry winter) had further accelerated the demand for water in irrigation. From 1980 to 2001, *Boro* production in West Bengal increased from 0.86 to 4.54 million tonnes (GoWB, 2003).

The rising demand of water for irrigation had been largely fulfilled by groundwater extraction. Between 1975/1976 and 1995/1996, groundwater irrigation has increased from 0.14 to 1.74 million hectares (GoI, 1998). During the same period, the density of groundwater irrigation wells (per 100 km^2) had increased from 298 to 952 (Rawal, 2001). In fact, the traditional patterns of irrigation (such as surface water from rivers, old canals, and water bodies) could not meet the high demand and lacked state patronage (Rawal and Swaminathan, 1998). Slowly their water storage

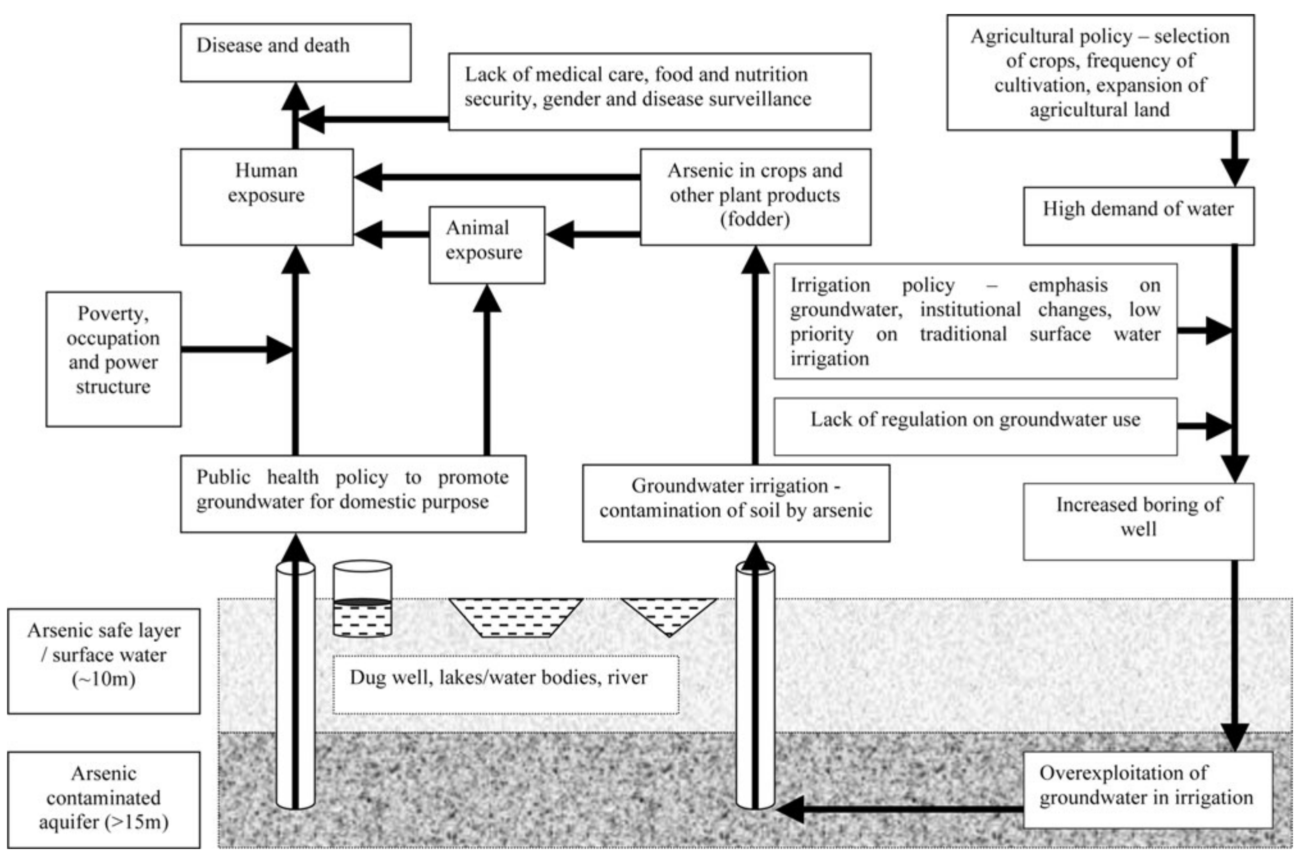

Figure 3. Conceptual framework of human arsenic exposure pathways.

potential was reduced due to silting and eventually the farmers became more dependent on groundwater. Due to political and social reasons, groundwater had been treated as a free commodity. In the absence of vigilance and legislation, government norms had been flouted flagrantly and hence there had been indiscriminate sinking of irrigation wells and extraction of groundwater beyond basic requirements (GoWB, 1993, 2005).

During the early 1970s, groundwater was promoted for drinking as an instrument of public health policy to prevent water-borne infectious diseases, such as diarrhea, cholera, amoebiasis, and other gastrointestinal diseases. According to the national census report of 2001, of 15.7 million households in West Bengal, two-thirds were dependent on groundwater for domestic use and although most of the remaining third used urban-supplied tap water, that was in fact mostly from underground sources (Banthia, 2003). Census reports also mentioned that 90% of the rural population in the arsenic-affected districts of West Bengal was dependent on groundwater for domestic use (Banthia, 2004).

The author had little scope to analyze arsenic exposure from food; other studies, however, found that food cooked in arsenic-contaminated water further increases exposure. Use of contaminated water in irrigation also polluted the topsoil in irrigated lands and arsenic subsequently entered the crops (Alam et al., 2003). The mean arsenic concentrations were higher in the soils of agricultural land irrigated with arsenic-contaminated water compared with fallow land soils (Roychowdhury et al., 2002). Vegetables that grew underground (tuber, potato) contained greater amounts of arsenic than other vegetables (Meharg, 2004). Most of the arsenic absorbed by plants was deposited in their roots followed by economic part (grains). However, the leaves also could be a potential source of arsenic for livestock if used as fodder. In fact, due to scarcity of grazing land in rural West Bengal, leaves and stems of agricultural plants had been the main source of fodder. The presence of arsenic in fodder could adversely affect cattle and subsequently human beings via the plant > animal > human pathway (Nandi et al., 2005). Analysis of arsenic intake through food and water showed that 20–40% of arsenic came from rice and vegetables (both cooked and raw) (Chowdhury et al., 2001). A study in Bangladesh showed that the intake of arsenic entering the body through food items is greater than the WHO's maximum limit with regard to drinking water (Molly et al., 2007).

Micronutrients and proteins were believed to have some protective role in occurrence of chronic arsenicosis. These nutrients were mostly available in pulses, animal products, green vegetables, and fruits. However, pulse production in West Bengal had declined from 0.24 million tonnes in 1980 to 0.17 million tonnes in 2003 and subsequently the price had increased, making them beyond the reach of the poor. From 1980/1981 to 2000/2001 vegetable production had increased from 4.7 to 7.5 million tonnes (GoWB, 2003). However, due to improved transportation facilities, locally produced green vegetables and fruits were being transported and sold to nearby cities and other states, and eventually they become nonavailable in the local markets or unaffordable to the poor.

The district health officials had initiated a decentralized plan for medical care, including the distribution of chelating agents and keratolytic ointments in peripheral health facilities of the affected areas. However, in the Jalangi county of Murshidabad district, the recurrence of symptoms was noticed after completion of treatment due to reexposure to arsenic (Rahman et al., 2005).

The recent mitigation strategy developed by the West Bengal Government essentially focused on: (1) short- and mid-term plans, such as arsenic filters fitted with hand pumps[6]; and (2) long-term plans, including a piped water supply after treating river water[7] and groundwater from deep wells. The strategy had rejected the earlier plan of using dug wells to avoid any possibility of water-borne disease (GoWB, 2009). However, there were examples in the state showing that chlorination, the most economical mode of water purification, could effectively provide safe drinking water from the dug wells. In fact, the arsenic task force of the Planning Commission of the Federal Government had recommended reintroduction of dug wells, rainwater harvesting, and slow sand filters for pond water as the supportive low-cost alternatives (GoI, 2007).

Discussion

Contamination of groundwater with arsenic is an increasingly severe ecological and public health issue in India. Existing research publications had provided a rich source of

[6]Arsenic-safe water was found beyond certain arsenic-contaminated aquifers and an effort has been made to identify them to supply potable water to the community. However, leaching from higher layers may contaminate the lower safe layers and hence arsenic removal plant (filter) is needed to ensure potable water.

[7]River and pond water are surface water and were found to be arsenic-free as their levels lie above arsenic aquifers (UNICEF, 2008).

information on epidemiology of chronic arsenicosis, medical treatment, agriculture policy, arsenic mitigation strategies, and their pros and cons. However, there had been no efforts to integrate this information to develop a sustainable strategy. Therefore, the interventions remained confined to biomedical approaches, such as provision of potable water supplies and medical care for the affected population. The author argues that inequity, current mode of agriculture practice, and drinking water policy have resulted in problems with mitigation strategies and that problems would worsen if these factors are not addressed in a larger policy framework.

Arsenic contamination has been spreading to newer areas and if the present trends continue, by 2010 approximately 450 million people living in the Ganga-Meghna-Brahmaputra basin, encompassing the affected Indian states and Bangladesh, will be at risk (Chakraborti et al., 2004). It had been estimated that lifelong ingestion of arsenic (1 μg/kg of body weight/day) is associated with an approximately 0.1% risk of skin cancer (Smith et al., 1992). This is very alarming as the level of arsenic contamination has been extremely high and its presence in multiple sources, such as foods and water, increases the opportunity for exposure. It had been predicted that in the large parts of southern Bangladesh, almost 1 in every 10 adult deaths in the coming decade will be a result of arsenic-induced cancer (Smith and Smith, 2004). Studies in Bangladesh had shown that lifetime mortality risks due to arsenic-related lung cancer of women and men were 23 and 159 per 100,000 respectively and bladder cancer of women and men were 0.3 and 5.4 respectively (Chen and Ahsan, 2004). A similar trend can be predicted for West Bengal and other affected states in India, because the nature and extent of the problem in this region are similar. This study showed the limited role of medical care due to technological constraint and a poor delivery system. Therefore, ecological management had become imperative to halt further human exposure. The conceptual framework (Fig. 3) discussed might contribute to identify interventions needed.

A piped water supply requires relatively high capital investment in installation and maintenance. Ironically, the dug wells had been rejected by some authorities, based on an argument of high risk of spreading of water borne diseases, and yet, a similar threat could be posed by piped water supply due to leakage in supply lines and contamination of sewage. Widespread use of arsenic filters could cause further damage to the local ecosystem due to unplanned open disposal of the highly toxic sludge produced after their use. This might pollute soil and surface water, currently the only source of arsenic-free water. Moreover, in many places the arsenic filters had failed to remove arsenic down to the desired limit (Hossain et al., 2005). This study has shown the role of socioeconomic disparity in high occurrence of chronic arsenicosis, poor coping, and lack of participation in decision making. However, such an important social issue has not been addressed in policy and there is a need to ensure greater participation of marginalized and highly affected communities. Lastly, the most significant gap in the strategy was an absence of intervention in agriculture policy, which had actually triggered the contamination. Perhaps, there is a need of empirical and conclusive evidence of the benefits of alternative agriculture policy in terms of interruption of further contamination to convince policy makers. It is recommended that future efforts address the challenge to generate credible evidence through multiple interventions supported by research and monitoring.

Acknowledgments

The research was supported by University Grants Commission, Government of India. The author thanks Dr. Ritu Priya (Jawaharlal Nehru University, New Delhi) for supervision of the research; Dr. P. Roy (Bose Institute, Kolkata), Prof. D. Chakraborti (Jadavpur University, Kolkata), and Prof. D.N. Guha Mazumdar (IPGMER, Kolkata) for technical support; and numerous volunteers in the study villages to facilitate in the data collection. The author acknowledges Prof. Gary vanLoon, Dr. Graham Whitelaw, and Kristan J. Hart (all from Queens University, Kingston), Nitya Nanda (The Energy and Resources Institute, New Delhi), and two anonymous referees for editing and helpful suggestions that greatly improved the manuscript.

References

Alam MG, Snow ET, Tanaka A (2003) Arsenic and heavy metal contamination of vegetables grown in Samta village, Bangladesh. *Science of Total Environment* 308:83–96

Asthana S, Gupta VM, Mishra RN (1998) Screening for obesity in affluent females: body mass index and it's comparison with skin fold thickness. *Indian Journal of Public Health* 42:37–41

Banthia JK (2004) *Housing Atlas of India 2001*, New Delhi, India: Census of India Office of Registrar General, pp 152–153

Banthia JK (2003) *Tables on Houses, Household Amenities and Assets*, New Delhi, India: Census of India 2001 Office of Registrar General, pp 445–446

Chakraborti D, Sengupta MK, Rahman MM, Ahamed S, Chowdhury UK, Hossain MA, et al. (2004) Groundwater arsenic contamination and its health effects in the Ganga-Meghna-Brahmaputra plain. *Journal of Environmental Monitoring* 6:74N–83N

Chen Y, Ahsan H (2004) Cancer burden from arsenic in drinking water in Bangladesh. *American Journal of Public Health* 94:741–744

Chowdhury UK, Rahman MM, Mondal BK, Paul K, Lodh D, Basu GK, et al. (2001) Groundwater arsenic contamination and human suffering in West Bengal, India and Bangladesh. *Environmental Science* 8:393–415

Ghatak M, Ghatak M (2002) Recent reforms in the panchayat system in West Bengal: toward greater participatory governance? *Economic and Political Weekly* 37:45–58

GOI (1998) *Water and Related Statistics*, New Delhi: Central Water Commission, Government of India, pp 14

GOI (2007) *The Task Force on Formulating Action Plan for Removal of Arsenic Contamination in West Bengal*, New Delhi: Planning Commission, Government of India, pp 1–51

GOWB (1993) *Circular: Agriculture (Minor Irrigation) Department*, Kolkata, India: State Water Investigation Department, Govt. of West Bengal

GOWB (2003) *West Bengal—Rural Development Special Issue (in Bengali)*, Kolkata, India: Department of Information and Culture, Govt. of West Bengal

GOWB (2005) *West Bengal Act XVIII of 2005: The West Bengal Ground Water Resources (Management, Control and Regulation) Act 2005*, Kolkata, India: The Kolkata Gazette, Govt. of West Bengal

GOWB (2009) *Future Arsenic Mitigation Program—a Master Plan*, Kolkata, India: Public Health Engineering Department, Government of West Bengal

Guha Mazumder DN, Haque R, Ghosh N, De BK, Santra A, Chakraborti D, et al. (1998) Arsenic levels in drinking water and prevalence of skin lesions in West Bengal, India. *International Journal of Epidemiology* 27:871–877

Haque R, Guha Mazumder DN, Samanta G, Ghosh S, Kalman N, Smith D, et al. (2003) Arsenic in drinking water and skin lesions: dose-response data from West Bengal, India. *Epidemiology* 14:174–182

Hartigan P (1999) *Communicable Diseases, Gender, and Equity in Health*. Working Paper Series No. 99.08, Cambridge: Harvard Centre for Population and Development Studies.

Hossain MA, Sengupta MK, Ahamed S, Rahman MM, Mondal D, Lodh D, et al. (2005) Ineffectiveness and poor reliability of arsenic removal plants in West Bengal, India. *Environmental Science and Technology* 39:4300–4306

Lebel J (2004) *Health—An Ecosystem Approach*, Ottawa, Canada: International Development Research Centre, pp 5–29

Meharg A (2004) Arsenic in rice—understanding new disaster for South East Asia. *Trends in Plant Science* 20:1–3

Mitra SR, Guha Mazumder DN, Basu A, Block G, Haque R, Samanta S, et al. (2004) Nutritional factors and susceptibility to arsenic-caused skin lesions in West Bengal, India. *Environmental Health Perspectives* 112:1104–1109

Molly LK, Houseman EH, Breton CV, Smith T, Quamruzzaman Q, Rahman M, et al. (2007) Dietary arsenic exposure in Bangladesh. *Environmental Health Perspectives* 115:889–893

Nandi D, Patra RC, Swarup D (2005) Arsenic residues in hair samples from cattle in some arsenic affected areas in West Bengal, India. *Bulletin of Environmental Contamination and Toxicology* 75:251–256

Nickson RT, McArthur JM, Ravenscroft P, Burgess WG, Ahmed KM (2000) Mechanism of arsenic release to groundwater, Bangladesh and West Bengal. *Applied Geochemistry* 15:403–413

Noronha L (2004) Ecosystem approaches to human health and well-being: reflections from use in a mining context. *Ecohealth* (*Special Supplement*) December

Project Well (PW) (2006) *Report on the Workshop 'Jawl Somporkay Alochana' Held on 26th November, 2006*. http://projectwellusa.org/whatsnew/Alochona26Nov06.pdf. Accessed 27 Feb 2010

Project Well (PW) (2009a) *Project Well Aqua Welfare Society Arsenic-Safe Water*. http://projectwellusa.org/Newsletters/NL_2009.pdf. Accessed 27 Feb 2010

Project Well (PW) (2009b) *Project Well Report on the 20 New Dug Wells Constructed in 2008: Gaighata*. http://projectwellusa.org/reportsnews/village_report_January_2009.pdf. Accessed 27 Feb 2010

Rahman MH, Al-Muyeed A, Ahmed A (2010) Arsenic catastrophe in Bangladesh: mitigation perspective and implementation challenges. *Asian Journal of Water, Environment and Pollution* 7:45–54

Rahman MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D, et al. (2001) Chronic arsenic toxicity in Bangladesh and West Bengal, India—a review and commentary. *Clinical Toxicology* 39:683–700

Rahman MM, Sengupta MK, Ahamed S, Chowdhury UK, Hossain MA, Das B, et al. (2005) The magnitude of arsenic contamination in groundwater and its health effects to the inhabitants of the Jalangi—one of the 85 arsenic affected blocks in West Bengal, India. *Science of the Total Environment* 338:189–200

Rapport DJ, Singh A (2006) An ecohealth-based framework for state of environment reporting. *Ecological Indicators* 6:409–428

Rawal V, Swaminathan M (1998) Changing trajectories: agricultural growth in West Bengal 1950–1996. *Economics and Political Weekly* 33:2595–2602

Rawal V (2001) Expansion of irrigation in West Bengal: mid 1970s to mid 1990s. *Economic and Political Weekly* 36:4017–4024

Roychowdhury T, Uchino T, Tokunaga H, Ando M (2002) Arsenic and other heavy metals in soils from an arsenic-affected area of West Bengal, India. *Chemosphere* 49:605–618

Smedley PL, Kinniburgh DG (2002) A review of the source, behaviour and distribution of arsenic in natural waters. *Applied Geochemistry* 17:517–568

Smith AH, Hopenhayn-Rich C, Bates MN, Goeden HM, Hertz-Picciotto I, Duggan HM, et al. (1992) Review of cancer risks from arsenic in drinking water. *Environmental Health Perspectives* 97:259–267

Smith AH, Smith MM (2004) Arsenic drinking water regulations in developing countries with extensive exposure. *Toxicology* 198:39–44

Smith MM, Hore T, Chakraborty P, Chakraborty DK, Savarimuthu X, Smith AH (2003) A dug well program to provide arsenic-safe water in West Bengal. *India: preliminary results Journal of Environmental Science and Health* A38:289–299

SOES (2010) *Groundwater Arsenic Contamination in Ganga-Meghna-Brahmaputra (GMB) Plain*. School of Environmental Studies, Jadavpur University, Kolkata, India. http://www.soesju.org/arsenic/arsenicContents.htm?f=ganga.htm. Accessed 26 Feb 2010

Stüben D, Berner Z, Chandrasekharam D, Karmakar J (2003) Arsenic enrichment in groundwater of West Bengal, India: geochemical evidence for mobilization of as under reducing conditions. *Applied Geochemistry* 18:1417–1434

UNICEF (2008) *Arsenic mitigation in Bangladesh.* United Nations Children Fund, Bangladesh, Dhaka. http://www.unicef.org/bangladesh/Arsenic.pdf. Accessed 2 Jan 2009

WHO (2005) *Ecosystems and Human Well-Being—Health Synthesis. Millennium Ecosystem Assessment*, Geneva: World Health Organization, pp 12–26