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COMMENTARY

An Eight-year Study Report on Arsenic Contamination in Groundwater and Health Effects in Eruani Village, Bangladesh and an Approach for Its Mitigation

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ABSTRACT

Based on several surveys during 1997-2005 and visits of a medical team to Eruani village, Laksham upazila, Comilla district, Bangladesh, the arsenic contamination situation and consequent clinical manifestations of arsenicosis among the villagers, including dermatology, neuropathy, and obstetric outcome, are reported here. Analysis of biological samples from patients and non-patients showed high body burden of arsenic. Even after eight years of known exposure, village children were still drinking arsenic-contaminated water, and many of them had arsenical skin lesions. There were social problems due to the symptoms of arsenicosis. The last survey established that there is a lack of proper awareness among villagers about different aspects of arsenic toxicity. The viability of different options of safe water, such as dugwells, deep tubewells, rainwater harvesting, and surface water with watershed management in the village, was studied. Finally, based on 19 years of field experience, it was felt that, for any successful mitigation programme, emphasis should be given to creating awareness among villagers about the arsenic problem, role of arsenic-free water, better nutrition from local fruits and vegetables, and, above all, active participation of women along with others in the struggle against the arsenic menace.

***Key words*:** Arsenic; Arsenic contamination; Groundwater; Skin lesions; Arsenical neuropathy; Obstetric outcomes; Mitigation; Bangladesh

INTRODUCTION

Our arsenic-related research over the last 19 years has established that the significant portions of the Ganga-Meghna-Brahamaputra (GMB) Plain in India and Bangladesh encompassing an area of 569,749 sq km with a population of over 500 million are at risk (1). Based upon the findings we anticipate arsenic contamination in groundwater on the floodplain areas of the rivers originating from the Himalayan and the Tibetan plateau. We first identified arsenic contamination in groundwater in the bordering areas of Bangladesh with West Bengal in 1992 (2). Analyzing around 52,000 water samples for arsenic from all 64 districts of Bangladesh, we found that, in 50 of the 64 districts, groundwater contained arsenic >50 µg/L, and more

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than 30 million people could be drinking water containing arsenic >50 µg/L (1).

Since 1997, the Governments of West Bengal (India) and Bangladesh, the World Bank, the United Nations Children's Fund (UNICEF), the World Health Organization (WHO), the Swedish International Development Cooperation Agency (Sida), the Danish International Development Agency (DANIDA), and other national and international aid agencies, launched a two-phase programme to curb the arsenic crisis. The first phase involved the screening of contaminated tubewells and the identification of safe ones in the arsenic-affected regions following the 50-µg/L standard. The second phase was to ensure supply of arsenic-safe drinking-water in the affected areas. Despite these laudable efforts and the few hundreds of millions of dollars already spent on arsenic mitigation, we came across many severely-affected villages in the GMB Plain, where the plight of villagers continues unabated.

We present here the on-the-ground realities of the arsenic contamination problem in Eruani village of Comilla district, Bangladesh. The selection was purposive. Results of analysis of water samples, analysis of biological samples, probabilistic estimates of the future-affected population, and clinical examinations of arsenic-related symptoms, including dermatology, neuropathy, and obstetric outcomes, among the villagers as revealed in our surveys in the Eruani village during 1997-2005 are presented here to show the dismal situation of many arsenic-affected villages in the GMB Plain. The probable solutions to curb this problem are also presented.

MATERIALS AND METHODS

Background of the study

We first surveyed Eruani village on 30 December 1997 with our medical team and analyzed 110 tubewell-water samples from the village. All the samples contained arsenic >50 µg/L. We also identified 40 patients with arsenical skin lesions, screening 200 people.

On 13 February 2000, we collected 140 water samples. All the samples had arsenic concentration above the WHO-recommended value of 10 µg/L and 137 (97%) >50 µg/L.

We analyzed 164 nail samples from the villagers with or without arsenical skin lesions during November 2003. Results of our analysis clearly showed (mean value=5,779 µg/kg) that the body burden of arsenic was quite high (98.8% samples had arsenic above the normal level), although about 50% of the subjects had no arsenical skin lesions.

During February 2004, our medical team screened 700 villagers, and 210 (30%) of them were identified with arsenical skin lesions. Of 97 water samples collected for analysis, arsenic concentration of >10 µg/L was found in 94 (96.9%) samples, while 92 (94.8%) samples had arsenic >50 µg/L (Bangladesh standard value). All 200 urine samples collected from the villagers contained arsenic above the normal level, ranging from 5 to 40 µg/1.5 L/day (3). We collected 122 nail samples from the villagers who had arsenical skin lesions; 99% of the samples had more than the above normal level ranging from 430 to 1,080 µg/kg (4).

After February 2004, the Dhaka Community Hospital (DCH) and School of Environmental Studies of Jadavpur University decided to conduct a detailed survey on the situation of arsenic contamination and the suffering of the people in Eruani village. A study was undertaken during 16 February 2004–18 April 2005.

Protocols for screening patients

We visited the village with our medical group based on prior information obtained from our field workers and results of water analysis. During these visits, we clinically examined persons who attended our medical camps. They consented to medical examinations and photography and also provided samples of urine, hair, and nails. The head-hair, nail, and spot-urine samples were collected immediately after their clinical examination. In a few cases, we visited their houses to examine subjects. We did not have any bar on the age of the subject.

Dermatological examination

Experienced dermatologists diagnosed arsenic dermopathy based on the features discussed in our previous publications (5). Detailed history and systemic examinations in arsenic-exposed persons having a combination of pigmentation (melanosis) and nodular rough skin (spotted palmo-plantar keratosis) almost always point to arsenic toxicity ruling out several isolated causes of melanosis or keratosis.

Neurological examination

Neurological observations were recorded for symptoms considered consistent with peripheral motor and also sensory neuropathy and for other neurologic abnormalities as well, stressing pain history and pain-specific sensory examinations. Based on the criteria

previously stated (6-8), clinical neuropathy was diagnosed. The diagnosis was ascertained by the presence of skin lesions and analyses of arsenic in hair, nail, and urine, along with the water they were drinking. Depending on the type of neuropathy, the cases were further categorized into sensory, sensorimotor, or motor types and according to severity into mild, moderate, or severe.

Obstetric survey

The study population consisted of women of reproductive age (18-40 years), who previously had had at least one pregnancy. The exposed group was from Eruani village and the non-exposed control group from the urban and sub-urban areas of Dhaka city. We collected information on residents' life-time pregnancy-history, including the number of pregnancies, spontaneous abortions, stillbirths, preterm births, and low birth-weight.

Social survey

During the field-visits, we carried out a random survey among the arsenic-affected population asking groups of people to fill in a questionnaire to judge their awareness of the arsenic problem.

Collection of samples and analysis of arsenic

The modes of water and biologic sample collection, the digestion procedures for hair and nail, and the analytical procedures were as reported earlier (9-10). Spot-urine samples were collected on a single occasion.

Hand-tubewell water, hair, nail and urine samples were analyzed for arsenic by flow-injection hydride generation-atomic absorption spectrophotometry (FI-HG-AAS). For urine samples, only inorganic arsenic and its metabolites together [arsenite–As(III), arsenate–As(V), monomethyl arsonic acid–MMA(V), and dimethyl arsinic acid–DMA(V)] were measured with no chemical treatment. Under the experiment conditions of FI-HG-AAS, arsenobetaine and arsenocholine do not produce a signal (9). For hair and nail samples, we determined total arsenic after digestion.

RESULTS

Arsenic in drinking-water

Figure 1 shows the location of Eruani village in Bangladesh. The total area of the village is 2.2 sq km, with a population of 6,690, and there were 193 hand-tubewells in total.

Figure 2a depicts the arsenic contamination status of the village on the basis of an analysis of all 193 hand-tubewell water samples by FI-HG-AAS. Only five tubewells were safe to drink according to the Bangladesh standard (50 μg/L), although none was safe by the WHO guideline value. Of these five tubewells, people did not use three tubewells due to the bad smell and high concentration of iron in water.

Arsenic in biological samples: sub-clinical effects

Concentration of arsenic in nail samples is an indicator of the body burden of arsenic, while urinary arsenic denotes recent arsenic exposure. During 2004-2005, we analyzed 311 nail, 25 hair, and 181 urine samples collected from villagers both with (60%) and without arsenical skin lesions (40%). In both the cases, more than 98% of the samples had arsenic above the normal level. Normal hair arsenic was 80-250 μg/kg, with 1,000 μg/kg considered to be a toxic level of arsenic in hair (11). Figure 2b-d summarize the body burden of arsenic among the villagers.

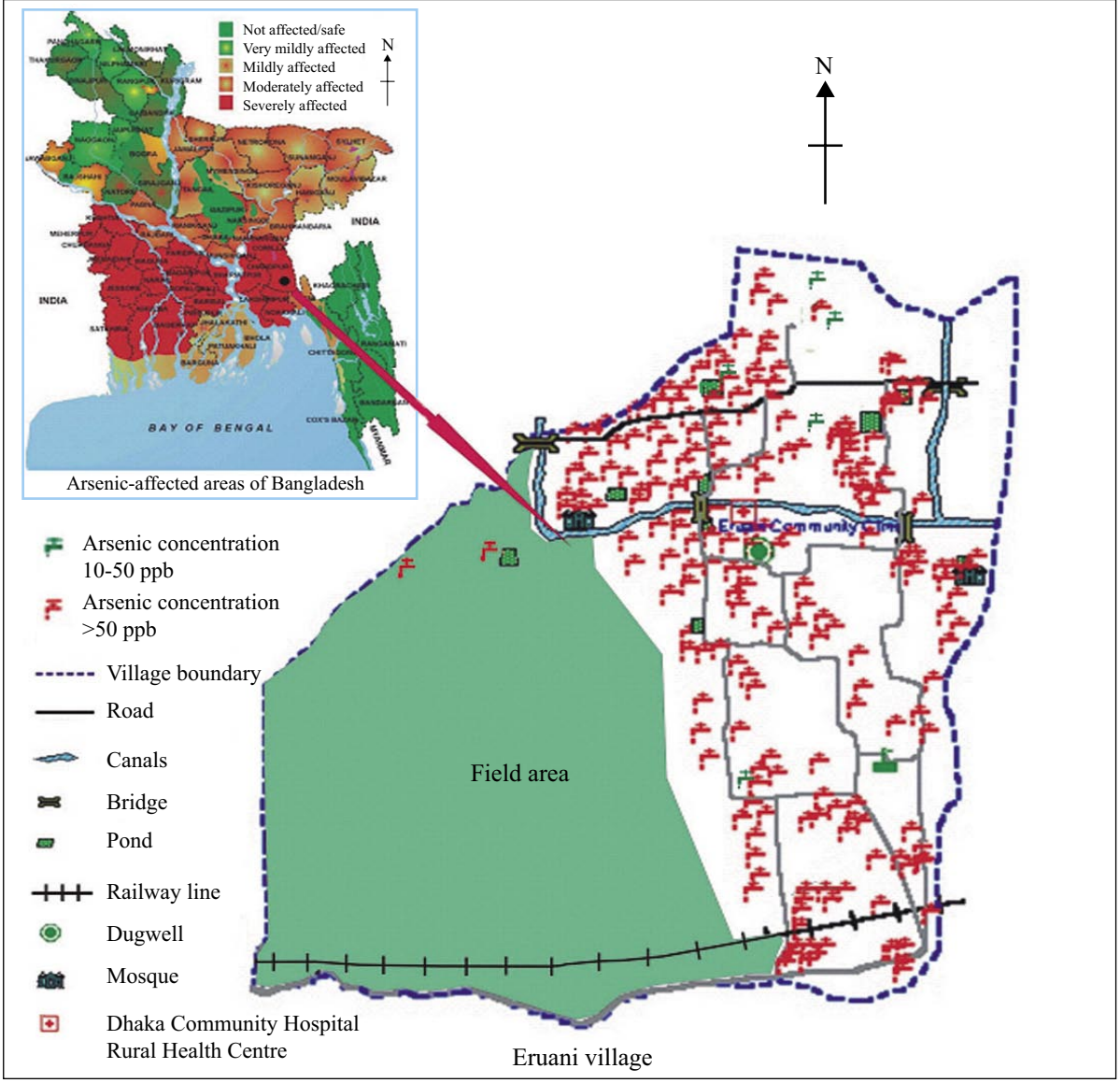
Dermatological effects of arsenic

In our latest survey in April 2005, of 1,580 adults screened, 395 (25%) revealed skin lesions. During our four clinical surveys, all possible arsenical skin lesions and toxicity symptoms were identified. These were: darkening of skin: diffuse melanosis; spotted pigmentation: spotted melanosis; white and black spots: leucomelanosis; mucus membrane melanosis, spotted and diffuse keratosis; and palpable nodules in dorsum of hands, feet, and legs: dorsal keratosis. Other symptoms were: conjunctional congestion; non-pitting swelling (oedema) of feet; hepatomegaly; spleenomegaly; ascites; Bowen's disease (suspected); and gangrene.

Figure 3 shows photographs of an arsenical patient taken in February 2000 and in February 2004. His health deterioration is noticeable. Concentration of arsenic in his drinking-water was 527 μg/L; his skin lesions in February 2000 and 2004 are presented in Table 1.

So, there is a continuing risk of getting arsenical skin lesions and, hence related diseases, if the villagers continue drinking water at the same level of arsenic unabated. Table 2 shows arsenical skin lesions of 22 patients from the village having suspected Bowen's disease, two of whom had suspected cancer. High content of arsenic in their biological samples (Table 2) showed that all these patients were still consuming high arsenic-contaminated water. Figure 4 shows the

Fig. 1. Eruani village: its location in Bangladesh and approximate locations of water sources in the village



photograph of an arsenic patient with suspected Bowen's disease, while Figure 5 shows the photograph of an arsenic patient with suspected cancer. Figure 6a-b show the photographs of arsenic patients with different types of arsenical skin lesions.

Arsenical neuropathy

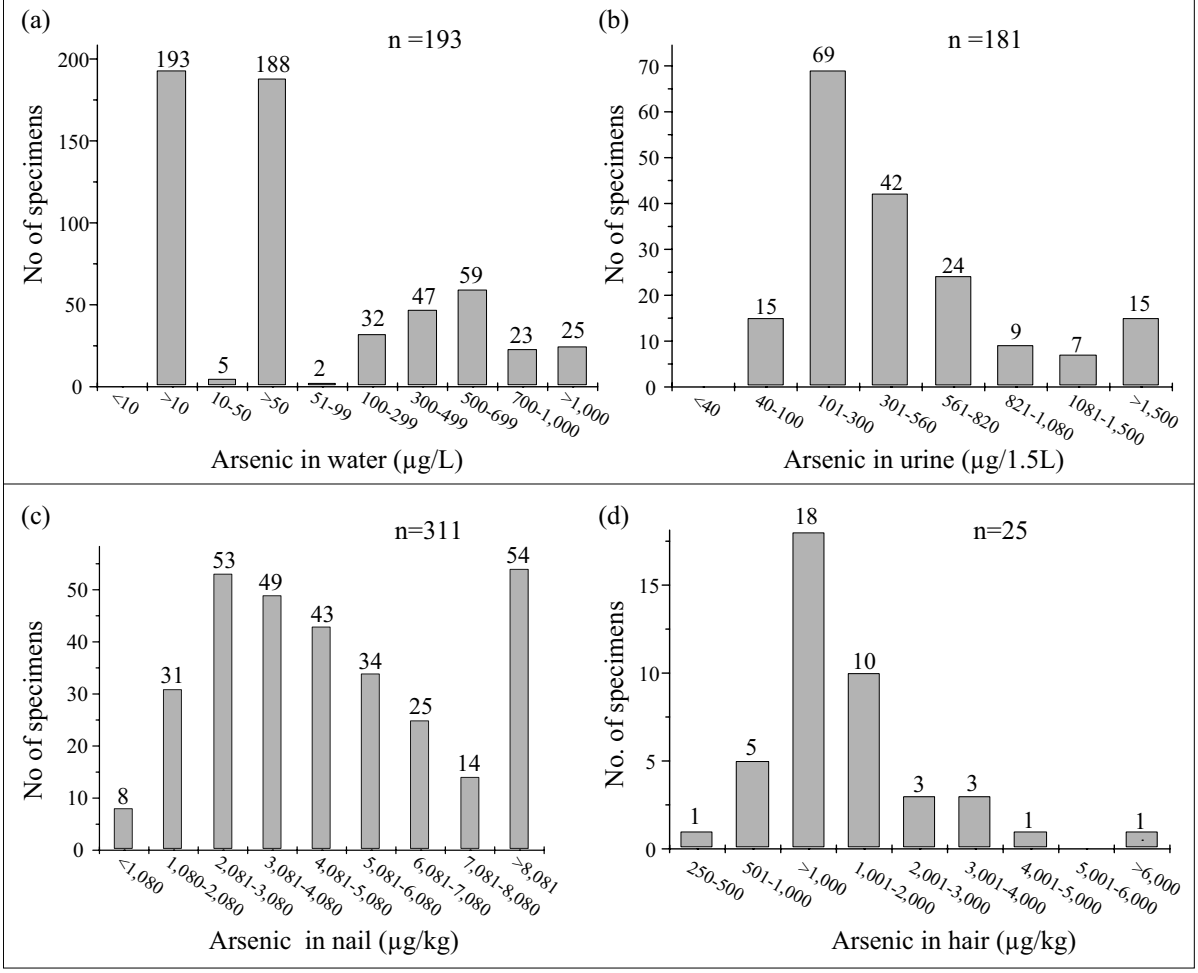
In total, 166 subjects (104 females and 62 males) were neuropathy patients; their age ranged from 9 to 80 years. There were 12 children aged up to 15 years. The range of arsenic in water, nail, and urine was 300 to 1,584 µg/L, 2,200 to 18,084 µg/kg, and 310 to 4,863 µg/1.5 L respectively. Of the 166 subjects neurologically screened, neuropathies from arsenic toxicity were identified in 100 (60.24%) subjects (Table 3). Figure 7 shows the photograph of an arsenical neuropathy patient.

The majority of the 166 subjects presented with sensory features of distal paresthesias (57.23%), limb pains (18.67%), and distal hypesthesias (46.98%) that outnumbered motor features of distal limb weakness or atrophy.

Arsenic in drinking-water and obstetric outcome

We calculated stillbirths and preterm births, using the total number of livebirths as a denominator and

Fig. 2. Arsenic contamination status of Eruani village and frequency distribution of biological samples from Eruani village



matched pregnancy outcomes of the respondents in both exposed and non-exposed groups (Table 4). The respondents of the exposed groups were categorized into group A and B according to low concentration (201-500 µg/L) and high concentration (501-1,200 µg/L) of arsenic in their drinking-water. The group C denoted the control population. Arsenical skin lesions were noted in two of four subjects in group A and 11 of 18 subjects in group B. Rates of spontaneous abortions and stillbirths increased in the exposed group. For preterm birth or labour, a high incidence was observed in group B respondents as also in the case of neonatal death.

Severe arsenical skin lesions

During our clinical survey, we identified 22 patients, with suspected Bowen's disease, who had severe arsenical skin lesions and two patients with non-healing ulcer (suspected cancer). Figure 8 shows the photograph of a patient with severe diffuse and spotted keratosis and gangrene.

Fig. 3. Photograph of the same arsenic patient taken in February 2000 and in February 2004 from Eruani village

Table 1. Dermatological features observed in the same arsenic patient in 2000 and 2004

Year	Age	Melanosis						Keratosis					Suspected Bowen's disease
		Palm		Trunk		Leu	WB	Palm		Sole		Dorsum	
		S	D	S	D			S	D	S	D		
2000	36	-	-	++	+	+	+	+++	++	+++	+	+	-
2004	40	+	++	+++	+++	++	++	+++	+++	+++	+++	++	+

+=Mild; ++=Moderate; +++=Severe; -=Not detected; D=Diffuse; Leu=Leucomelanosis; S=Spotted; WB=Whole body

Arsenical effects in children

Infants and children are often more susceptible to the adverse effects of toxic substances than adults (12-13). Our study children in Eruani were also exposed to high level of arsenic (in biological samples), and 8.6% of 186 children screened had arsenical skin lesions. Figure 9 (a-h) shows the photographs of a group of children who were drinking arsenic-contaminated water ranging from 500 to 1,100 µg/L during our last survey in April 2005. Of these, six had arsenical skin lesions, and all had higher level of arsenic in nails (1,818-10,488 µg/kg).

Table 2. Dermatological features of a group of people from Eruani village with severe arsenical skin lesions and arsenic level in their biological samples

Patient's ID no.	Sex/ age (years)	Melanosis						Keratosis					Bowen's disease	Arsenic concentration		
		Palm		Trunk		Leu	WB	Palm		Sole		Dorsum		Water (µg/L)	Urine (µg/1.5 L)	Nail (µg/kg)
		S	D	S	D			S	D	S	D					
1	F/50	-	-	++		++	++	++	+	++	+	+	+	526	200	2,275
2	M/45	+	+	++	+	+	+	+	+	+	+	+	+	589	300	4,059
3	M/45	+	+	++	+	++	+++	+++	++	+++	++	+	+	619	290	N/A
4	M/42	-	-	++	+	++	+	++	+	+++	++	-	+	619	N/A	800
5	F/50	+	+	++	+	+	+	+	+	+	+		+	689	153	4,012
6	F/50	-	-	++	++	++	++	++	++	++	++	-	+	N/A	75	1,864
7	M/30	+	+	++	+	+	++	++	+	++	+	-	+	120	220	2,631
8	M/40	++	++	+++	+++	+	++	+++	+++	+++	+++	++	+	Pond*	N/A	N/A
9	F/60	-	-	+	+	+++	+++	++	++	+	++	+	+	242	150	2,721
10	F/40	-	-	+	+	+	-	++	+	+	+		+	844	N/A	2,259
11	F/40	-	-	+	+	+		+	+	+	+		+	904	84	N/A
12	F/40	-	-	++	++	+	+	+	+	+	+	+	+	962	335	18,084
13	F/35	-	-	++	++	+	+	+	+	+	+		+	962	153	1,428
14	F/70	-	-	+	+	+	+	+	+	+	+	-	+	N/A	230	N/A
15	F/35	-	+	+	+	+	+	+	+	+	+	-	+	120	460	3,634
16	F/30	-	-	+	+	+	+	-	+	+	+	-	+	N/A	822	12,970
17	F/60	-	-	+	+	+	+	+	+	+	+	+	+	489	529	N/A
18	F/65	-	-	++	+	++	+	++	+				+	304	N/A	N/A
19	F/60	-	-	+	-	++	++	++	-	+	++	+	+	580	94	2,252
20	F/60	-	-	++	+	++	++	+	+	+	++	++	+	384	141	13,073
21	F/45	-	-	+	+	+	-	+	-	-	+	+	+	360	169	5,152
22	F/40	+	+	++	++	+	+	+	+	+	+	+	+	770	279	4,871

*At the time of survey, the patient was consuming pond water; +=Mild; ++=Moderate; +++=Severe; -=Not detected; D=Diffuse; F=Female; M=Male; Leu=Leucomelanosis; S=Spotted; WB=Whole body; N/A=Not available during sampling

Fig. 4. Photograph of an arsenic patient with suspected Bowen's disease

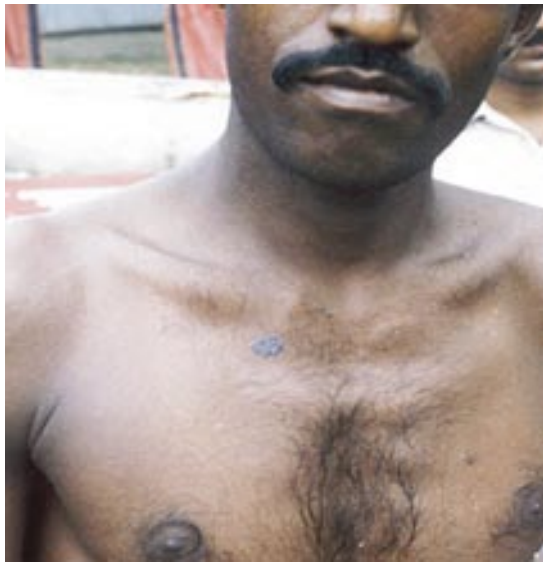


Fig. 5. Photograph of an arsenic patient with suspected cancer

Fig. 6. (a) An arsenic-affected child patient with spotted melanosis and (b) An arsenic patient with spotted and diffuse keratosis on the sole

Fig. 7. Photograph of an arsenical neuropathy patient

Fig. 8. Photograph of one arsenic patient with severe diffuse and spotted keratosis and gangrene from Eruani village

Social problems due to arsenic contamination

There were common social problems due to arsenic toxicity as we have observed through a random survey from all over the GMB Plain (14). In Eruani, apart from the above-mentioned problems, a particular case is described below.

Mr. Nurul Miah had arsenical skin lesions and his daughter Selina Aktar too. Sirajul Islam married Selina as he required money to go to the USA. After some years, he returned to the village and divorced Selina and married again. Even during our survey, all the family members were drinking their hand-tubewell water [concentration of arsenic=542 µg/L].

Table 3. Prevalence, severity, and type of arsenic neuropathy among patients in Eruani village

Prevalence	Subject	No. of patients examined	No. of patients with neuropathy					
	Female	104	64 (61.54)					
	Male	62	36 (58.06)					
	Children*	12	4 (33.33)					
	Total	166						
Severity			Mild neuropathy			Moderate neuropathy		
	Female	104	54 (51.92)			10(9.62)		
	Male	62	30 (48.39)			6 (9.67)		
	Children*	12	4 (33.33)			-		
	Total	166	84 (50.60)			16 (9.64)		
Type			Sensory			Sensorimotor		
			Mild	Moderate	Total	Mild	Moderate	Total
	Female	104	51 (49.04)	7 (6.73)	58 (55.77)	3 (2.88)	3 (2.88)	6 (5.76)
	Male	62	25 (40.32)	3 (4.84)	28 (45.16)	5 (8.06)	3 (4.84)	8 (12.90)
	Children*	12	4 (33.33)	-	4 (33.33)	-	-	-
	Total	166	76 (45.78)	10 (6.02)	86 (51.80)	8 (4.82)	6 (3.61)	14 (8.43)

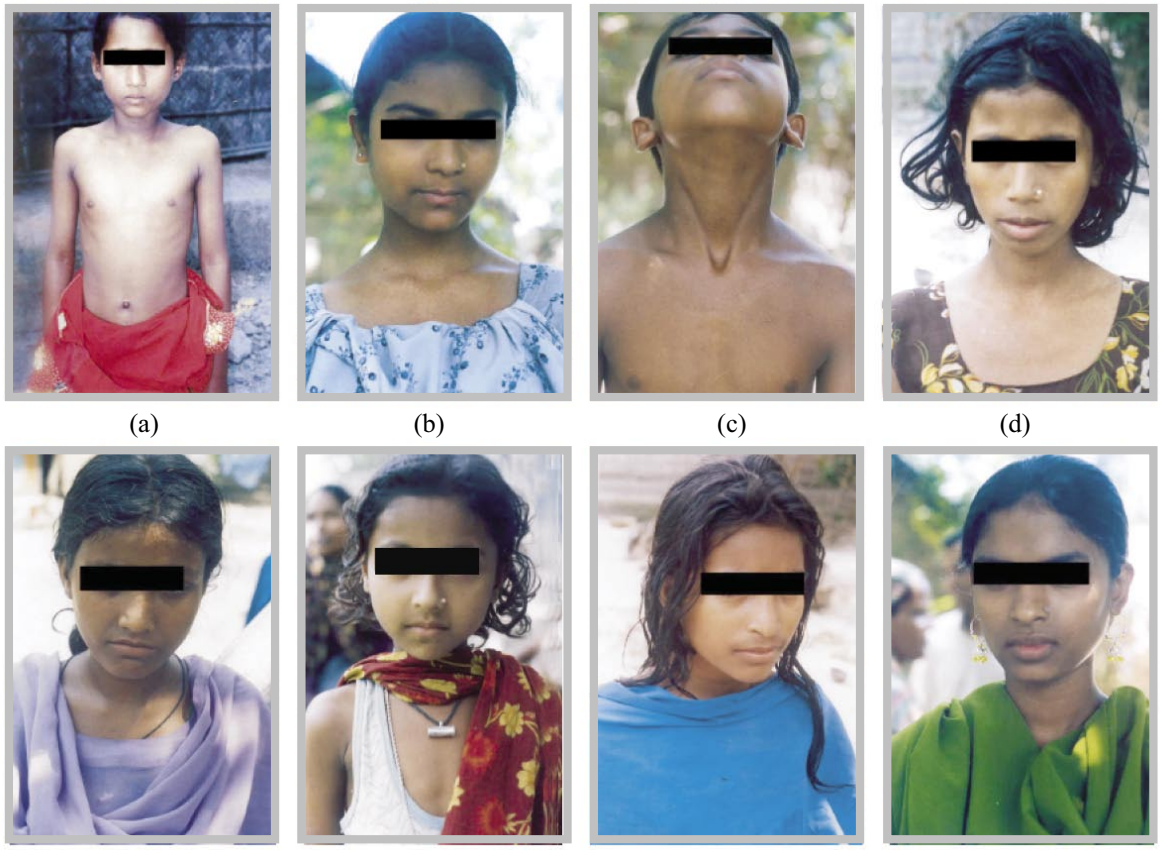
*Aged up to 15 years
Figures in parentheses indicate percentages

Table 4. Arsenic in drinking-water and pregnancy outcome*

Parameter	Exposed group A 201-500 (µg/L) (n=4)	Per 1,000 livebirths	Exposed group B 501-1,200 (µg/L) (n=18)	Per 1,000 livebirths	Non-exposed group C (n=18)	Per 1,000 livebirths
Skin lesion	2		11		Nil	
Number of pregnancies	10		56		47	
Spontaneous abortion (per 1,000 pregnancies)	2	200	15	267.86	8	170.21
Stillbirth (per 1,000 total births)	2	250	7	170.73	2	51.28
Preterm birth	-	-	5	147.06	1	27.03
Low birth-weight	1	166.67	8	235.29	2	54.05
Neonatal death	1	166.67	7	205.88	5	135.14
Range of arsenic in hair (µg/kg)	867-3,067		567-4,684			
Range of arsenic in nail (µg/kg)	1,010-6,440		1,001-12,914			
Range of arsenic in urine (µg/1.5 L)	860-3,892		15-3,992			

*Calculations have been done as mentioned in Williams Obstetrics (15)

Fig. 9. Photograph of a group of children who were still consuming arsenic-contaminated water during the last visit of the medical team in Eruani village



DISCUSSION

The grave arsenic contamination in Eruani village is evident from our analytical results (Fig 2a). Before our survey, the villagers were not aware of the arsenic contamination situation. The plight of Eruani village can be compared with Rajapur village of Domkal block in Murshidabad district, West Bengal (16), Semria Ojha Patti of Shahpur block in Bhojpur district of Bihar (16), Chayan Chapra village of Belhari block in Ballia district, Uttar Pradesh, India (18) as described in our previous publications.

The results (Fig. 2b-d) from biological samples suggest that, irrespective of skin lesions, the villagers had elevated levels of arsenic in biological samples. Thus, many villagers may be sub-clinically affected.

Chronic exposure to arsenic causes a characteristic pattern of dermal effects that might start with melanosis (pigmentation) to keratosis and hyperkeratosis (19,20). It has been observed that when keratosis and melanosis appear together they point to arsenical toxicity. Details about arsenical skin lesions have been discussed earlier (12,21). As there are several diseases mimicking arsenic dermatosis, care should be taken in confirming the arsenical effect (5). The prevalent severe skin lesions among the villagers prove that the situation has not improved even after eight years of discovering arsenic contamination in Eruani.

The incidence of neuropathy was higher (60.24%) in the present study compared to our earlier observations in chronically-exposed persons (37.3%) (20), but was lower than that observed in a small population of sub-acute cases (22). The reason for this higher incidence may be the fact that most of the 166 subjects were continuing consumption of arsenic-contaminated water at the time of our survey.

Effects of arsenic exposure on several obstetric endpoints, such as spontaneous abortions, high rate

of stillbirths, preterm births, low birth-weight, and prenatal and neonatal mortality were earlier reported (1,23-26). All these features were corroborated in our study in Eruani. However, the influence of other confounders in these arsenic-exposed subjects needs to be explored.

Infants and children are considered to be more susceptible to the adverse effects of some toxic substances (12). Several studies (27-28) have shown that children are at higher risk of arsenic exposure. If children face higher risk, the future of the next generation in arsenic-affected villages in the GMB Plain appears to be grim.

Different safe-water options and their relative viability in Eruani village are discussed below.

Tubewells: In Eruani, arsenic in the range of 10-50 µg/L was found in 193 hand-tubewells, three shallow (depth ≤30 m), and two somewhat deeper tubewells (70 and 85 m) [Fig. 2a], but the tubewells in the depth range of 70-85 m were not safe. In most (n=193) hand-tubewells, iron was quite high (mean 3,291, median 2,435, minimum 503, maximum 48,773 µg/L). So, hand-tubewells may not provide potable water to the villagers. Moreover, periodic testing for arsenic in existing safe tubewells is essential as arsenic may increase with time (29). However, on an experimental basis, one deep tubewell (above around 400 m) may be installed as we know tubewells from this depth are usually free of arsenic (30).

Rainwater harvesting: Rainwater harvesting is a technology used for collecting and storing rainwater from rooftops, the land surface, or rock catchments using simple techniques, such as jars and pots, and more complex techniques, such as underground check dams. In many states of India and southern parts of Bangladesh, rainwater harvesting is still a common practice. The average annual rainfall in eastern part of Bangladesh is about 2,000 mm. Although the Eruani people do not follow this practice, they may be taught about it, and they can use it for 4-6 months.

Surface water with proper watershed management: In Eruani, there are no river or big surface-water resources. Although plenty of ponds are available, the water is too dirty to be used for drinking. Extensive purification and expensive treatment may help, but due to drying up of water in the summer months, these cannot provide water throughout the year. Thus, in the present situation, we do not recommend surface water as a solution for the village.

Dugwells: During our last survey in Eruani, there were two dugwells: (a) one, arsenic-safe (20 µg/L), installed by the Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP), is no longer usable due to improper maintenance; and (b) the DCH dugwell is maintained by the villagers, and they contribute to its maintenance. Periodic analysis over the last three years proved that it is free of arsenic (range 8-20 µg/L). Sixteen families use this dugwell. However, due to small diameter of the dugwell (≈1 m diameter), the quantity of water during the summer is not enough for 16 families.

From the above two examples combined with our dugwell experience in the arsenic-affected Dangapara village in Nadia district, West Bengal, Uttar Pradesh, Bihar and Jharkhand states of India, it appears that if 4-5 big dugwells (3-4 m in diameter), if erected properly, regularly cleaned, kept free of bacteria, and carefully maintained with people's participation, dugwells could be successful in Eruani.

Arsenic-removal plant: A large-scale arsenic-removal plant may be successful in Eruani with people's participation. From our long field experience, we have observed that the success of arsenic-removal plants largely depends on their proper maintenance.

Whatever be the choice for safe-water option, the role of better nutrition and community participation is prerequisite for any successful mitigation strategy. In areas with severe arsenic-related health effects due to ingestion of drinking-water with high concentrations of arsenic (southwestern Taiwan and the Antofagasta region of Chile), inhabitants were reported to have low socioeconomic and nutritional status (31,32). A recent study in arsenic-affected areas in West Bengal has shown that low intake of calcium, folate, fibre, and animal protein increased susceptibility to arsenical skin lesions (33).

Villagers need to be properly educated about the danger of arsenic in drinking-water, the necessity of arsenic removal, role of better nutrition, and available safe-water options. One of our random surveys (n=100) in Eruani showed that, although around 90% of the villagers were aware of the arsenic problem, around 80% were unaware of its seriousness. They often ignore mild arsenical skin lesions and are totally unaware of evil effects of arsenic on children and pregnant women. Since most of the time males are away at work and women are in charge of household activities, creating awareness among women should be stressed.

Strengths and limitations of the study

This study tried to highlight the scenario of arsenic contamination in Eruani based on 193 tubewell water samples used for drinking and cooking. Analyses of data correlated this with clinical manifestations, such as dermatological, neurological and obstetric effects as observed by the medical experts and also sub-clinical manifestations, such as high concentrations of arsenic in the biological samples of the villagers. The findings of the study indicate the social effects of arsenic toxicity. It also attempts to evaluate the alternative safe options available for the villagers and suggests measures to be taken to tackle the menace. Eruani is an example of such villages, where the suffering of villagers has continued unabated over the last eight years. This paper serves to highlight their cause to the scientific community and to remind them of the urgent need of safe water for a large population like the villagers in Eruani.

In looking at the multi-faceted nature of the arsenic problem, we did have some limitations. First, this was not an epidemiological study as we could not carry out a sufficiently elaborate survey. Second, although we have mentioned about suspected Bowen's disease and cancer in the text, we could not substantiate our claim by pathological reports. From anecdotal reports, we gathered that about 100 people who had arsenical skin lesions died, and many of them were young. Of them, at least 10-15 people might have died of cancer. However, we did not have enough evidence to show that, because in the villages of the GMB Plain, death registry is not a prerequisite for burial. The reasons behind some of these limitations as revealed during our discussion with the villagers were: (a) in the rural areas, the affected people often considered the disease as contagious and were afraid of social isolation on revealing their ailment; (b) young girls and women of conservative families did not want to be examined; (c) people who were physically weak and suffering extensively could not travel long distance to come to our medical camp; and (d) generally, we visited the villages during day time, when most adult males were working in the fields, and several young boys and girls were attending school. In the survey for obstetric outcomes, women were generally reluctant to discuss reproductive history, which restricted the sample size.

The analysis of water and biological samples, and clinical survey comprising dermatological, neurological, and obstetric study revealed that, despite repeatedly highlighting the groundwater arsenic-contamination situation of Eruani village since its discovery in 1997, the situation has not improved, and the villagers are still drinking contaminated water. A viable safe-water option coupled with awareness about the arsenic problems is urgently required.

REFERENCES

1. Chakraborti D, Sengupta MK, Rahman MM, Ahamed S, Chowdhury UK, Hossain MA *et al.* Groundwater arsenic contamination and its health effects in the Ganga-Megna-Brahmaputra Plain. *J Environ Monit* 2004;6:74N-83N.
2. Dhar RK, Biswas BK, Samanta G, Mandal BK, Chakraborti D, Roy S, Jafar A *et al.* Groundwater arsenic calamity in Bangladesh. *Current Sci* 1997;73:48-59.
3. Farmer JG, Johnson LR. Assessment of occupational exposure to inorganic arsenic based on urinary concentrations and speciation of arsenic. *Br J Ind Med* 1990;47:342-8.
4. Ioanid N, Bors G, Popa I. Beitage zur kenntnis des normalen arsengehaltes von nageln and des Gehaltes in den Faillen von Arsenpolyneuritits. *Dts Zeits Gesamte Gerichtl Med* 1961;52:90-4 [German].
5. Saha KC. Diagnosis of arsenocosis. *J Environ Sci Health Part A Tox Hazard Subst Enviorn* 2003;38:255-72.
6. Feldman RG, Niles CA, Kelly-Hayes M, Sax DS, Dixon WJ, Thomson DJ *et al.* Peripheral neuropathy in arsenic smelter workers. *Neurology* 1979;29:939-44.
7. Kreiss K, Zack MW, Feldman RG, Niles CA, Chirico-Post J, Sax DS *et al.* Neurologic evaluation of a population exposed to arsenic in Alaskan well water. *Arch Environ Health* 1983;38:116-21.
8. Galer BS. Painful polyneuropathy. *In*: Backonja MM, editor. Neuropathic pain syndromes; neurologic clinics. Philadelphia: Saunders, *Neurol Clin* 1998;16:791-812.
9. Chatterjee A, Das D, Mandal BK, Chowdhury TR, Samanta G, Chakraborti D. Arsenic in ground water in six districts of West Bengal, India: the biggest arsenic calamity in the world. Part I. Arsenic species in drinking water and urine of the affected people. *Analyst* 1995;120:643-50.

10. Samanta G, Chowdhury TR, Mandal BK, Biswas BK, Chowdhury UK, Basu GK *et al.* Flow injection hydride generation atomic absorption spectrometry for determination of arsenic in water and biological samples from arsenic affected districts of West Bengal, India and Bangladesh. *Microchem J* 1999; 62:174-91.

11. Arnold HL, Odom RB. James WD. *In*: Andrew's disease of the skin: clinical dermatology. 8th ed. Philadelphia: Saunders, 1990:121-2.

12. U.S. National Research Council. Subcommittee on Arsenic in Drinking Water. Arsenic in drinking water. Washington, DC: National Academy Press, 1999. 310.

13. Wasserman GA, Liu X, Parvez F, Ahsan H, Levy D, Factor-Litvak P *et al.* Water arsenic exposure and children's intellectual function in Araihazar, Bangladesh. *Environ Health Perspect* 2004;112:1329-33.

14. Chowdhury UK, Rahman MM, Mandal BK, Paul K, Lodh D, Biswas BK *et al.* Groundwater arsenic contamination and human suffering in West Bengal, India and Bangladesh. *Environ Sci* 2001;8:393-415.

15. Gary CF, Gant NF, Leveno KJ, Gilstrap LC, Hauth JC, Wenstrom KD, editors. Williams Obstetrics. 21st ed. New York: McGraw Hill, 2001:691.

16. Rahman MM, Sengupta MK, Ahamed S, Chowdhury UK, Lodh D, Hossain MA *et al.* Arsenic contamination in groundwater and its health impact on residents in a village in West Bengal, India. *Bull World Health Org* 2005;83:49-57.

17. Chakraborti D, Mukherjee SC, Pati S, Sengupta MK, Rahman MM, Chowdhury UK *et al.* Arsenic groundwater contamination in middle Ganga Plain, Bihar, India: a future danger? *Environ Health Perspect* 2003;111:1194-201.

18. Ahamed S, Sengupta MK, Mukherjee A, Hossain MA, Das B, Nayak B *et al.* Arsenic groundwater contamination and its health effects in the state of Uttar Pradesh (UP) in upper and middle Ganga Plain, India: a severe danger. 2006. (http://www.sciencedirect.com/science/journal/00489697, accessed on 20 November 2005).

19. Mandal BK, Roy Chowdhury T, Samanta G, Basu GK, Chowdhury PP, Chanda CR *et al.* Arsenic in groundwater in seven districts of West Bengal, India—the biggest arsenic calamity in the world. *Curr Sci* 1996;70:976-86.

20. Rahman MM, Chowdhury UK, Mukherjee SC, Mondal BK, Paul K, Lodh D *et al.* Chronic arsenic toxicity in Bangladesh and West Bengal, India—a review and commentary. *J Toxicol Clin Toxicol* 2001;39:683-700.

21. National Research Council. Arsenic in drinking water: 2001 update. Washington, DC: National Academy Press, 2001:27-30.

22. Mukherjee SC, Rahman MM, Chowdhury UK, Sengupta MK, Lodh D, Chanda CR *et al.* Neuropathy in arsenic toxicity from groundwater arsenic contamination in West Bengal, India. *J Environ Sci Health A Tox Hazard Subst Environ Eng* 2003;38:165-83.

23. Nordstrom S, Beckman L, Norenson I. Occupational and environmental risks in and around a smelter in northern Sweden. V. Spontaneous abortion among female employees and decreased birth weight in their offspring. *Hereditas* 1979;90:291-6.

24. Ahmad SA, Sayed MH, Barua S, Khan MH, Faruquee MH, Jalil A *et al.* Arsenic in drinking water and pregnancy outcomes. *Environ Health Perspect* 2001;109:629-31.

25. Aschengrau A, Zierler S, Cohen A. Quality of community drinking water and the occurrence of spontaneous abortion. *Arch Environ Health* 1989; 44:283-90.

26. Yang CY, Chang CC, Tsai SS, Chuang HY, Ho CK, Wu TN. Arsenic in drinking water and adverse pregnancy outcome in an arseniasis-endemic area in northeastern Taiwan. *Environ Res* 2003;91:29-34.

27. Smith AH, Marshal G, Yuan Y, Ferreccio C, Liaw J, Ehrenstein OV *et al*. Increased mortality from lung cancre and bronchiectasis in young adults after exposure to arsenic in utero and in early childhood. *Environ Health Perspect* 2006;114:1293-96.

28. Concha G, Nermell B, Vahter M. Metabolism of inorganic arsenic in children with chronic high arsenic exposure in northern Argentina. *Environ Health Perspect* 1998;106:355-9.

29. Chakraborti D, Basu GK, Biswas BK, Chowdhury UK, Rahman MM, Paul K *et al.* Characterization of arsenic bearing sediments in Gangetic delta of West Bengal, India. *In*: Chappell WR, Abernathy CO, Calderon RL, editors. Arsenic

exposure and health effects. Amsterdam: Elsevier Science, 2001:27-52.

30. Chakraborti D, Biswas BK, Basu GK, Chowdhury UK, Chowdhury TR, Lodh D *et al.* Possible arsenic contamination free groundwater source in Bangladesh. *J Surface Sci Technol* 1999;15:180-8.

31. Borgono JM, Vicent P, Venturino H, Infante A. Arsenic in the drinking water of the city of Antofagasta: epidemiological and clinical study before and after the installation of the treatment plant. *Environ Health Prespect* 1977;19:103-5.

32. Hsueh YM, Cheng GS, Wu MM, Yu HS, Kuo TL, Chen CJ. Multiple risk factors associated with arsenic-induced skin cancer: effects of chronic liver disease and malnutritional status. *Br J Cancer* 1995;71:109-14.

33. Mitra SR, Mazumdar DN, Basu A, Block G, Haque R, Samanta S *et al.* Nutritional factors and susceptibility to arsenic-caused skin lesions in West Bengal, India. *Environ Health Perspect* 2004;112:1104-9.