Status of groundwater arsenic contamination and human suffering in a Gram Panchayet (cluster of villages) in Murshidabad, one of the nine arsenic affected districts in West Bengal, India

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ABSTRACT

A detailed study was carried out in a cluster of villages known as Sagarpara Gram Panchayet (GP), covering an area of 20 km^2 and population of 24,419 to determine the status of groundwater arsenic contamination and related health effects. The arsenic analysis of all hand tubewells (n = 565) in working condition showed, 86.2% and 58.8% of them had arsenic above 10, and 50 $\mu g\,l^{-1}$, respectively. The groundwater samples from all 21 villages in Sagarpara GP contained arsenic above 50 $\mu g\,l^{-1}$. In our preliminary clinical survey across the 21 villages, 3,302 villagers were examined and 679 among them (20.6%) were registered with arsenical skin lesions. A total of 850 biological samples (hair, nail and urine) were analysed from the affected villages and, on average, 85% of them contained arsenic above the normal level. Thus, many people of Sagarpara might be sub-clinically affected. Our data was compared with the international one to estimate population in Sagarpara GP at risk from arsenical skin lesions and cancer. Proper watershed management and economical utilization of available surface water resources along with the villagers' participation is urgently required to combat the present arsenic crisis.

Key words | arsenical skin lesions, arsenic in biological samples, arsenic in children, groundwater arsenic contamination, people at risk from arsenic toxicity, Sagarpara GP

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INTRODUCTION

Twenty-three incidents of groundwater arsenic contamination have been reported so far in different parts of the world. The largest population at risk is in Bangladesh (Rahman *et al.* 1999; Chowdhury *et al.* 2000; Smith *et al.* 2000; Milton *et al.* 2001; Rahman *et al.* 2001; Van Geen *et al.* 2003) followed by the state of West Bengal in India (Guha Mazumder *et al.* 1992, 1998; Mandal *et al.* 1998; Chowdhury *et al.* 2000, 2001; Rahman *et al.* 2001, 2003; Chakraborti *et al.* 2002). In recent years evidence of arsenic groundwater contamination has also emerged in other Asian countries including Lao PDR, Cambodia, Myanmar and Pakistan (ESCAP-UNICEF-WHO Expert Group Meeting 2001). Groundwater arsenic contamination and associated skin lesions have also been reported from Nepal (Tendukar *et al.* 2001; Shrestha *et al.* 2003), Vietnam (Berg *et al.* 2001), the Kurdistan province of Iran (Mosaferi *et al.* 2003) and the state of Bihar (Chakraborti *et al.* 2003) in the Middle Gangetic Plain in India. Recently with the discovery of arsenic in the groundwater in other states in India including Uttar Pradesh, Jharkhand and Assam (Chakraborti *et al.*

10.2166/wh.2005.038

2004) and combining these with previously reported arsenic incidents in northern India (Datta 1976), West Bengal and Bangladesh, it appears that some areas in all states and countries of India and Bangladesh in the Ganga-Meghna-Brahmaputra (GMB) plain, with a population of over 450 million and area 570,000 km^2 might be at risk from groundwater arsenic contamination.

The first case of arsenic poisoning in West Bengal, India, was reported in 1984 (Garai *et al.* 1984; Chakraborti *et al.* 2002). It was in 1988 that our team initiated a survey of the arsenic affected villages of West Bengal. Since then, for 16 years now, we have been conducting analytical, clinical and epidemiological studies in the arsenic affected areas of West Bengal to determine the magnitude of arsenic contamination. To date we have analysed more than 129,000 hand tubewell water samples and about 28,000 biological samples (urine, hair, nail and skin-scale) for arsenic and we have screened 92,000 people for arsenical skin lesions from the arsenic affected villages of West Bengal (Chakraborti *et al.* 2004). Out of a total of 18 districts in West Bengal, we have so far identified 3,200 villages from 85 blocks in 9 districts as being arsenic affected (Chakraborti *et al.* 2004). Our results showed that 49.6% of the hand tubewells had arsenic above 10 $\mu g\,l^{-1}$ (the WHO guideline value for safe levels of arsenic in drinking water) and 24.7% above 50 $\mu g\,l^{-1}$ (the Indian standard of permissible level of arsenic in drinking water).

The WHO recommended value of arsenic in drinking water of 10 $\mu g\,l^{-1}$ is based on 2 l of water consumption per day, while in most developing countries the permissible level of arsenic in drinking water is 50 $\mu g\,l^{-1}$. West Bengal and Bangladesh are both tropical regions where the average water consumption of an adult could be as high as 4 l per day while those who work in fields (in India and Bangladesh at least 60–70% of rural people are farmers) consume a much larger quantity of water (Chowdhury *et al.* 2001). For children below 11 years of age the average water consumption is 2 l per day (Chowdhury *et al.* 2001). Thus on the basis of the WHO guideline, the recommended amount of arsenic in drinking water for villagers of West Bengal and Bangladesh should be 5 $\mu g\,l^{-1}$ or less. The reasons why the permissible amount of arsenic in drinking water in developing countries is 50 $\mu g\,l^{-1}$ are unknown. The number of patients registered so far with arsenical skin lesions from the nine arsenic affected districts of West Bengal is 8,900 and, an average, 78% of the biological samples from the populations of these villages showed arsenic above the normal level (Chakraborti *et al.* 2004). Therefore there is a possibility that a large number of these villagers were sub-clinically affected.

The total area of West Bengal is about 89,193 km^2 and the population is about 80 million. The nine arsenic affected districts cover about 38,865 km^2 and the population is about 50 million. From the extrapolation of our generated data, we estimated that more than 8 million people may be drinking arsenic contaminated water of concentration above 10 $\mu g\,l^{-1}$, more than 6 million above 50 $\mu g\,l^{-1}$ and about 0.5 million people may suffer from arsenical skin lesions in the nine affected districts of West Bengal (Chakraborti *et al.* 2004).

On the basis of our 16 years of water analysis data from nine arsenic affected districts of West Bengal, we may consider the districts of 24 Parganas (north), Nadia, Murshidabad and Malda as highly arsenic contaminated; 24 Parganas (south) as moderately affected; and the districts Bardhaman, Howrah, Hugly and Kolkata as less affected. Even after working for so many years we feel we have covered only a small portion of the affected areas and additional affected villages are being identified with virtually every new survey. We feel our present research may be only the tip of the iceberg of the full extent of arsenic contamination in West Bengal.

To better understand the status of arsenic contamination of groundwater and its impact on people's health, we decided to concentrate on a single district of West Bengal. As we had a larger amount of preliminary information from, as well as local field workers in, Murshidabad, we decided to select this district for our detailed survey. However, eventually Murshidabad proved to be too large a district for a thorough survey, so we decided to cover only one cluster of villages (known as Gram Panchayet, GP) out of the 70 similarly affected GPs in Murshidabad for our detailed survey. We randomly selected Sagarpara GP for our study.

In this article we describe in detail the status of the Sagarpara GP in the Murshidabad district including: (i) the arsenic contamination status of the groundwater of Sagarpara and an estimation of the population exposed to various levels of arsenic; (ii) the arsenic in the biological samples from the villagers in Sagarpara; (iii) the clinical observations and suffering of the people due to arsenic toxicity; and (iv) the probable estimate of the population size that may suffer from arsenical skin lesions and cancer in Sagarpara by comparing our data with international data.

MATERIALS AND METHODS

Description of the study area

The state of West Bengal in eastern India comprises 18 districts. Each district is further divided into several blocks/police stations (PS). Each block again is composed of several clusters of villages known as Gram Panchayet (GP) and each GP has several villages.

Sagarpara is one of the 10 GPs in the Jalangi block. Figure 1 shows the position of the arsenic affected areas of Murshidabad in West Bengal, the arsenic affected areas of Jalangi block and our study area, Sagarpara GP in Jalangi block. In the Sagarpara GP there are 21 villages. The total area of Sagarpara is 20 km^2 and the population is about 24,419.

Instrumentation

The flow injection hydride generation atomic absorption spectrometry (FI-HG-AAS) method was used for arsenic analysis. Details of the instrumentation and the flow injection system have been described in our earlier publications (Chatterjee *et al.* 1995; Das *et al.* 1995; Samanta & Chakraborti 1997; Samanta *et al.* 1999).

Sample collection and arsenic analysis

We spent 320 man-hours (4 persons × 8 hours × 10 days) on the collection of water and biological samples from Sagarpara GP.

Hand tubewell water, hair, nail and urine samples were analysed for arsenic by the FI-HG-AAS method. For urine samples, only inorganic arsenic and its metabolites (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 experimental conditions of FI-HG-AAS, arsenobetaine and arsenocholine do not produce a signal (Chatterjee *et al.* 1995). Hair and nail samples were analysed for total arsenic after digestion. The modes of water and biological samples collection, the digestion procedures for hair and nail and the analytical procedures were as reported earlier (Chatterjee *et al.* 1995; Das *et al.* 1995; Samanta & Chakraborti 1997; Samanta *et al.* 1999).

Quality assurance and quality control programme

For quality control, inter-laboratory tests were performed for water and hair samples as reported in our earlier publications (Samanta *et al.* 1999; Rahman *et al.* 2002). We had also analysed EPA water standard and biological standard reference materials including hair and urine for arsenic, which have been reported elsewhere (Samanta & Chakraborti 1997; Samanta *et al.* 1999, 2000).

Screening of villagers for arsenical skin lesions

We spent 7 days with 2–3 medical personnel including a dermatologist for screening people with arsenical skin lesions and other arsenic related health effects. Normally before visiting a village with our medical team for screening, we would analyse water from that village's hand tubewells, usually collected beforehand by our expert field workers, who also made a rough estimation of the families there suffering from arsenical skin lesions. We set up seven camps in 21 villages of the Sagarpara GP for examining the villagers. On our arrival in the affected villages, a few volunteers through loud speakers would inform the villagers that a medical team from Kolkata would examine their skin-related illness due to arsenic toxicity. Our medical team examined those who visited our camps. An experienced dermatologist recorded the signs and symptoms of arsenical skin lesions.

Estimation of population drinking contaminated water at various concentration levels of arsenic

To determine the number of people of Sagarpara GP who might have consumed arsenic contaminated water at various concentration levels of arsenic, we made a simple

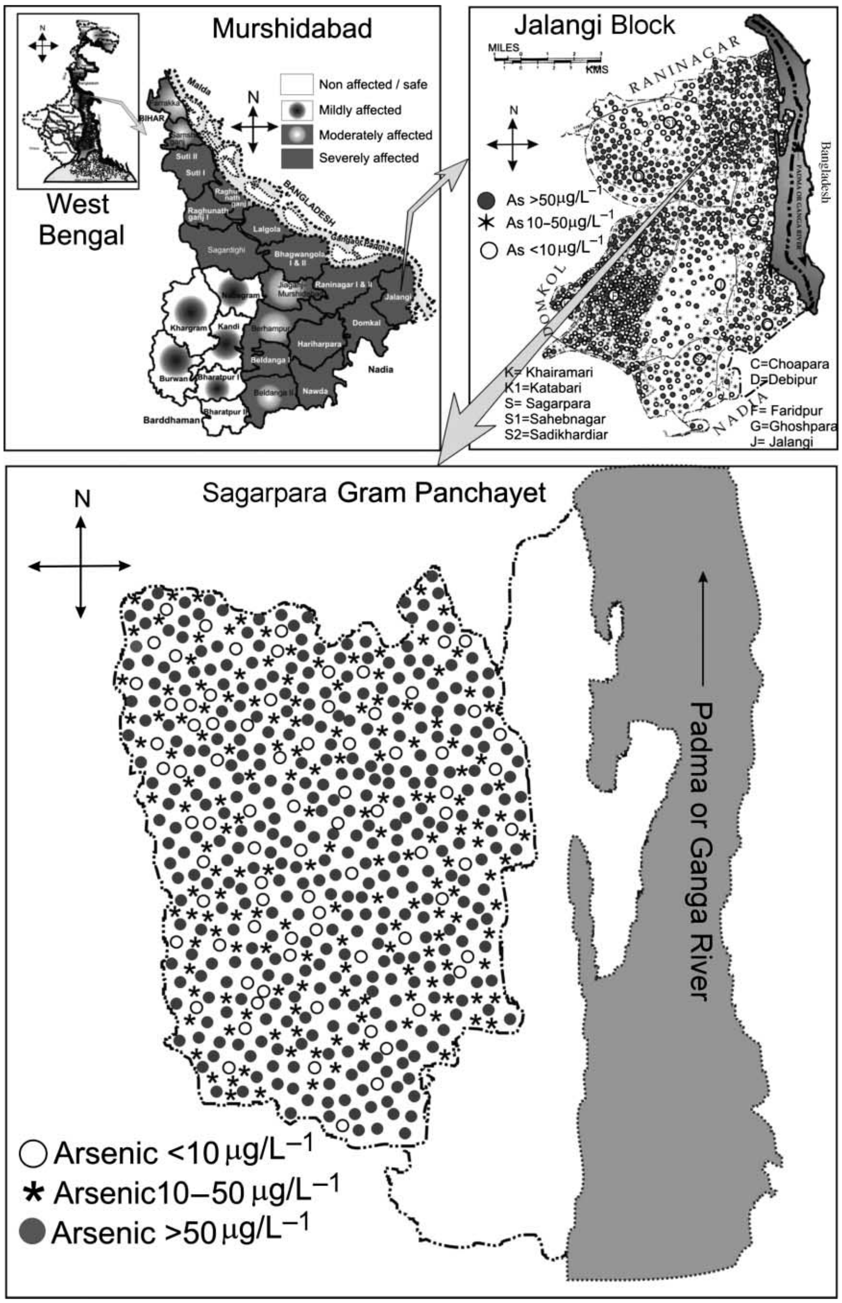

Figure 1 | The location of the arsenic affected areas of West Bengal in India, the arsenic affected areas of the Murshidabad district, the arsenic affected areas of Jalangi block and our study area, Sagarpara Gram Panchayet (GP) and groundwater arsenic contamination status of Sagarpara GP.

calculation. We had analysed 83% of the total hand tubewells (17% of tubewells were defunct during our survey) of Sagarpara and from our field survey report we also knew the number of users per hand tubewell in Sagarpara. Thus by determining the arsenic concentration of each tubewell we could estimate the number of people drinking contaminated water at various concentration levels of arsenic. In our previous study we have proved the validity of such calculations (Rahman *et al.* 2003).

RESULTS AND DISCUSSION

Arsenic in the hand tubewells of the Sagarpara GP and the number of villagers drinking arsenic contaminated water at various concentration levels

A summary of the arsenic status report of Sagarpara GP is presented in Table 1. During our survey of Sagarpara GP, we found that there were 679 hand tubewells in 21 villages. Of these, we could collect samples for arsenic analysis from only 565 (83.2%) hand tubewells. The other 114 tubewells were defunct. During our survey, villagers were drinking water from the 565 functional hand tubewells. The villagers informed us that 10–15% of the total tubewells were always defunct. Our field survey information shows that almost 100% of the villagers of Sagarpara GP use hand tubewell water for drinking. As the total population of this GP is 24,419, we estimated that there were 43 people to one hand tubewell during our survey.

Figure 1 shows the arsenic contamination status of 565 hand tubewells in Sagarpara GP and Table 2 presents the distribution of arsenic in hand tubewells analysed from 21 villages of the Sagarpara GP. From Table 2, it appears that 86.2% of the water samples contained arsenic at concentrations above $10\,\mu g\,l^{-1}$ and 58.8% contained above $50\,\mu g\,l^{-1}$. Only 13.8% of hand tubewells during our study were safe to drink from based on the WHO guideline value for arsenic. The analytical results of water samples also revealed that the groundwater of all 21 villages contained arsenic above $50\,\mu g\,l^{-1}$ (Table 2). Table 3 shows the probable estimation of population in Sagarpara GP exposed to arsenic contaminated water at various concentration levels of arsenic. During our 16 years of field experience in West Bengal and 8 years in Bangladesh, we have reported that ingestion of arsenic above $300\,\mu g\,l^{-1}$ in drinking water for a couple of years may produce arsenical skin lesions in adults (Rahman *et al.* 2003).

Out of the 21 villages of Sagarpara GP, there are four villages where 80–90% of the hand tubewells were contaminated with arsenic at above $50\,\mu g\,l^{-1}$. Chakchaitan-Ghoshpara is an example of one such village. The total population of this village was about 800 during our survey and all the villagers were getting their drinking water from 23 hand tubewells. We analysed all 23 tubewells and found 2 tubewells had arsenic at 21 and $27\,\mu g\,l^{-1}$ and the rest had arsenic above $100\,\mu g\,l^{-1}$. The maximum arsenic concentration so far estimated from this village is $1{,}574\,\mu g\,l^{-1}$ and 82.6% of the analysed hand tubewells contained arsenic above $300\,\mu g\,l^{-1}$. Before our survey villagers were not aware of the arsenic contamination of the water they were drinking from their hand tubewells. They were also not aware that their skin lesions were due to arsenic toxicity. However there were also some villages where groundwater arsenic contamination was not so high (Table 2).

Table 1 | Status of groundwater arsenic contamination in Sagarpara GP of Murshidabad

Physical parameters	Sagarpara
Total area in km^2	20
Total population	24,419
Number of villages including sub-villages	21
Number of villages surveyed	21
Total number of hand tubewells	679
Number of hand tubewells water samples analysed	565 (83.2%)
% of samples having arsenic above $10\,\mu g\,l^{-1}$	86.2
% of samples having arsenic above $50\,\mu g\,l^{-1}$	58.8
% of samples having arsenic above $300\,\mu g\,l^{-1}$	26.5
% of samples having arsenic above $500\,\mu g\,l^{-1}$	13.3
% of samples having arsenic above $1{,}000\,\mu g\,l^{-1}$	4.2
Number of villages where we have found arsenic above $50\,\mu g\,l^{-1}$	21
Number of villages surveyed for arsenic patients	21
Number of villages where we identified arsenic patients	21
People screened for arsenical skin lesions by our medical team	3,302
Registered arsenic patients (preliminary survey)	679 (20.6%)

Table 2 | Distribution of hand tubewell water samples at different arsenic concentration ranges ($\mu g\,l^{-1}$) in Sagarpara GP of Murshidabad*

Name of the village	Total water samples analysed	Distribution of water samples in different arsenic concentration range ($\mu g\,l^{-1}$)										Maximum arsenic concentration found ($\mu g\,l^{-1}$)
		<3	3–9	<10	10–50	51–99	100–299	300–499	500–699	700–1,000	>1,000	
Azimpur	18	–	–	–	6	2	5	5	–	–	–	457
Baromasia	38	4	2	6	8	13	4	3	3	–	1	658
Chak Mathura	36	2	4	6	10	7	7	2	–	2	2	1,083
Chakchaitan	16	–	–	–	4	–	2	1	3	5	1	1,222
Chakchaitan Damospara	18	–	–	–	1	8	5	2	1	1	–	771
Chakchaitan Ghoshpara	23	–	–	–	2	–	2	7	2	6	4	1,574
Godagari	44	–	1	1	10	6	11	6	4	–	6	1,386
Godagari Thakurpara	10	–	–	–	3	1	2	4	–	–	–	485
Jubbar Colony	4	–	–	–	1	2	–	1	–	–	–	389
Mallickpara	11	–	–	–	–	1	8	2	–	–	–	428
Narasinghapur	20	3	1	4	8	4	3	1	–	–	–	346
Nawdapara	58	2	–	2	14	8	16	11	5	1	1	1,176
Nilambarpara	68	12	7	19	27	2	14	4	1	1	–	851
Pulpara	21	–	–	–	5	5	6	3	2	–	–	557
Ramnarayanpur	10	–	1	1	3	–	2	3	1	–	–	622
Roypur	16	–	1	1	4	–	2	3	2	3	1	1,073
Sagarpara	28	6	6	12	15	1	–	–	–	–	–	60
Sakerdiyar	38	3	–	3	4	4	9	12	2	2	2	1390
Suryanagar Colony	28	4	4	8	11	6	1	1	–	1	–	869
Udaynagar Colony	52	4	10	14	18	5	6	4	–	1	4	2,040
Uttar Ghoshpara	8	1	–	1	1	1	1	–	2	–	2	1,157
Total (21)	565	41	37	78	155	76	106	75	28	23	24	

*During our survey in all villages, some of the tubewells were defunct.

Table 3 | Population drinking arsenic contaminated water at various concentration levels in Sagarpara GP of Murshidabad district

Population of Sagarpara GP	Number of hand tubewells analysed	People drinking arsenic contaminated water									
		<10 $\mu g\,l^{-1}$	>10 $\mu g\,l^{-1}$	>50 $\mu g\,l^{-1}$	>100 $\mu g\,l^{-1}$	>125 $\mu g\,l^{-1}$	>200 $\mu g\,l^{-1}$	>250 $\mu g\,l^{-1}$	>300 $\mu g\,l^{-1}$	>500 $\mu g\,l^{-1}$	>1,000 $\mu g\,l^{-1}$
24,419	565	3,354	20,640	14,276	11,008	10,363	8,557	7,224	6,321	3,182	1,032

Arsenic in biological samples

Arsenic has an affinity for the sulfhydryl group (-SH) present in keratin. So arsenic accumulates in keratin-rich tissues such as skin, hair and nail. Thus arsenic levels in skin, hair and nail may be used as an indicator of arsenic exposure. Arsenic level in urine has been regarded as the most reliable indicator of recent exposure to inorganic arsenic (ATSDR 1993; Kurttio *et al.* 1998). Experimental studies show that around 60–75% of the dose is excreted through the urine within a few days (Tam *et al.* 1979; USEPA 1988; Vahter 1994) and our observations show that approximately 70% of arsenic is released through urine from the body within 30 hours of consumption (Mandal *et al.* 1998). Arsenic concentration in hair and nail plays an important role in evaluating the arsenic body burden.

During our field survey in the affected villages of Sagarpara GP, we had collected and analysed 301 hair, 382 nail and 176 urine samples. About 50% of the samples were from persons with arsenical skin lesions and the rest were from those without skin lesions but living in the same arsenic affected villages. We analysed the total arsenic content for hair and nail and the inorganic arsenic and its metabolites (sum of inorganic arsenic + MMA + DMA) in urine. The analytical results of hair, nail and urine samples are presented in Table 4. From Table 4, it appears that 93% of nail and 91% of urine samples contained arsenic above the normal level and 76% of the hair samples contained arsenic above the toxic level. The normal levels of arsenic in hair, nail and urine are also presented in Table 4. It also appears from Table 4 that many villagers not exhibiting arsenical skin lesions may still have elevated levels of arsenic in their hair, nail and urine. This indicates that many villagers might be sub-clinically affected.

Table 4 | Concentration of arsenic in hair, nail and urine (metabolites) collected from Sagarpara GP of Murshidabad district

Parameters	Arsenic concentration in hair ($\mu g\,kg^{-1}$)	Arsenic concentration in nail ($\mu g\,kg^{-1}$)	Arsenic concentration in urine ($\mu g\,(1.5\,l)^{-1}$)
Normal level (range)	80–250[a] (Arnold *et al.* 1990)	430–1,080 (Ioanid *et al.* 1961)	5–40[b] (Farmer & Johnson 1990)
No. of observations	301	382	176
Mean	2,291	5,071	271
Median	1,864	8,576	163
Range	222–15,021	611–27,892	33–2,420
Standard deviation	1,723	4,534	312
% of samples having arsenic above normal/toxic (hair) level	76	93	91

[a]1000 μg/kg is the indication of toxicity; [b]per day.

Clinical observations

We have identified people with arsenical skin lesions from all 21 villages of the Sagarpara GP. To date we have screened 3,302 people from all 21 villages and registered 679 (20.6%) people including children with arsenical skin lesions (489 males, 173 females and 17 children). Figure 2 shows the percentage of prevalence against dermatological symptoms of the registered patients. During our 16 years of field experience in West Bengal and 8 years in Bangladesh, we noticed that children under 11 years of age usually did not show arsenical skin lesions although their biological samples contained high levels of arsenic (Chowdhury *et al.* 2000; Rahman *et al.* 2001). However, we observed exceptions in cases when: (i) arsenic content in water consumed by the children was very high ($\geq$ 1,000 $\mu g\,l^{-1}$); and (ii) arsenic content in drinking water was not so high (around 500 $\mu g\,l^{-1}$), but the children suffered from malnutrition (Chowdhury *et al.* 2000; Rahman *et al.* 2001). In these cases, either diffuse or light spotted melanosis was observed. Sometimes mild keratosis was also noted. But in Sagarpara, keratosis on palms and soles were not rare in children. In Sagarpara, we examined 500 children for arsenical skin lesions and of them 17 (3.4%) were registered with arsenical skin lesions.

The dermatological and other symptoms of arsenic toxicity observed among the villagers of Sagarpara were:

(i) Darkening of the skin (diffuse melanosis) was found on the entire body or on the palms. This is usually the earliest symptom, though it is not always necessary that people suffering from arsenic toxicity should have the symptom of diffuse melanosis.
(ii) Spotted pigmentation (spotted melanosis/raindrop pigmentation) was also seen on the chest, back or limbs. This is a very common symptom.
(iii) Leucomelanosis is white and black spots side by side, also seen in some patients. Leucomelanosis is common in patients who have stopped drinking arsenic contaminated water but who had spotted melanosis earlier.
(iv) Buccal mucus membrane melanosis on the tongue, gums and lips (diffuse, patchy or spotted melanosis) were found in some cases.
(v) Diffuse or nodular or both keratosis on the palms and soles were noticed among villagers. Keratosis is a late feature of arsenical dermatosis (exceptions are found). The skin becomes dry and thickened owing to diffuse keratosis. There is gradual thickening of the soles producing hyperkeratotic cracks and fissures.
(vi) Rough, dry skin, often with palpable nodules (spotted keratosis) on dorsal side of hands, feet and legs was also noticed. This is a symptom seen in severe cases.

A combination of pigmentation (melanosis) and nodular rough skin (spotted palmoplantar keratosis) almost always

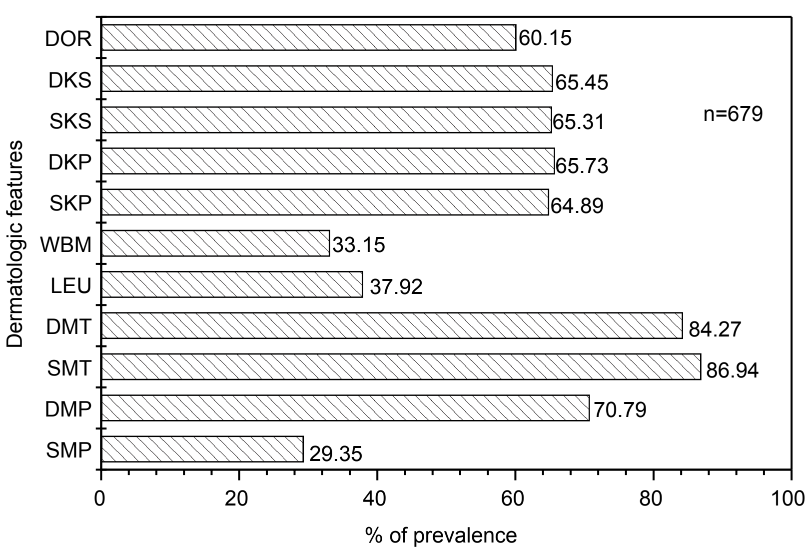

Figure 2 | Percentage of prevalence of dermatological involvement manifested by the arsenicosis patients from Sagarpara GP.

points to arsenic toxicity, excluding hundreds of other causes of isolated pigmentation and nodular rough skin (Saha & Chakraborti 2001).

Other symptoms in some of the patients are conjunctional congestion and non-pitting swelling (solid oedema) of the feet. We have also noticed some findings that were not previously reported in association with arsenicosis. For example, 70–75% of the patients with arsenical skin lesions from Sagarpara GP and other arsenic affected villages reported severe itching on exposure to sunlight even in winter.

Cases such as liver enlargement (hepatomegaly), spleen enlargement (splenomegaly) and fluid in the abdomen (ascites) were observed among some patients. Non-healing ulcer (suspected skin cancer, Figure 3) and suspected Bowen's disease were noted. We had no information about other forms of internal cancer. That does not eliminate the possibility of internal cancers. Table 5 shows the dermatological features of 10 severe arsenicosis patients of Sagarpara GP. During our survey of all villages of the Sagarpara GP, as some of the tubewells were defunct, we were unable to measure the arsenic concentration of these tubewells and determine the arsenic exposure of those villagers who normally used these tubewells.

Figure 3 | An arsenicosis patient with keratosis and non-healing ulcer from Nilambarpara village of Sagarpara GP.

Probable estimation of the population that may suffer from arsenical skin lesions and cancer in Sagarpara GP by comparing with international data

On the basis of the data generated in Table 3 on the population drinking arsenic contaminated water at various levels in Sagarpara GP and from the information available in literature we have tried to estimate the population in the Sagarpara GP that may suffer from arsenical skin lesions and cancer. Our calculations are presented in Table 6.

These values in Table 6 are an approximation and the actual number of people suffering in Sagarpara may be much lower as many are now aware of which tubewells are arsenic contaminated and which are safe to drink from. Further alternative safe water sources are being installed in the affected villages. We had also assumed that arsenic in the water in the contaminated hand tubewells was present from when they had first been installed. We were unable to determine the time period over which arsenic contamination of these tubewells had occurred or for how long the villagers may have been drinking arsenic contaminated water. Our previously published studies showed (Chakraborti *et al.* 2001; Sengupta *et al.* 2004) that, within a span of 3–7 years in many villages, tubewells that had initially been safe ($<10\,\mu g\,l^{-1}$) were later found to be contaminated ($>50\,\mu g\,l^{-1}$). It was also found that the arsenic concentration in many tubewells had increased by as much as 5–20 fold (Chakraborti *et al.* 2001; Sengupta *et al.* 2004).

From our field experience we observed that villagers normally did not drink from the same tubewell. Adults and children stayed outside their homes for 8–12 hours a day. We had also to consider that children below 11 years of age exhibited fewer arsenical skin lesions. Further, four important interrelated factors that needed to be considered for the appearance of the arsenical skin lesions but that we could not account for are: (i) how long an individual had been drinking from that tubewell; (ii) how much he or she consumed daily; (iii) the concentration of arsenic in the drinking water; and (iv) his or her nutritional status. As our dose response relation studies (Chowdhury *et al.* 2000;

Table 5 | Dermatological features of 10 people with severe arsenical skin lesions from Sagarpara GP of Murshidabad district

		Melanosis						Keratosis							
		Palm		Trunk		Leu	WB	Palm		Sole					
Name of the village	Sex and age	S	D	S	D			S	D	S	D	Dorsal	Chronic bronchitis (years)	Bowen's disease	Suspected carcinoma
Chakchaitan	M/50	−	+	++	+	+	+	++	+	++	+	−	−	–	Cancer
Chakchaitan	F/50	+	++	+	+	+	−	++	+	++	+	+	−	–	Cancer
Godagari	M/30	−	−	++	+	+	−	++	+	+	+	−	–	–	Cancer
Nilambarpara	F/50	+	+	++	+	+	+	++	+	++	+	−	10	–	Cancer
Nilambarpara	M/62	−	−	++	+	+	−	+	+	++	+	−	10	–	Cancer
Nawdapara	M/38	−	−	++	+	+	−	++	++	++	++	–	20	–	–
Chakchaitan	M/45	−	+	++	++	+	+	++	++	++	++	–	16	+	–
Jubbar Colony	M/28	−	+	++	++	+	+	++	++	++	++	–	13	–	–
Nilambarpara	F/50	+	+	++	+	+	+	++	+	++	+	–	10	–	–
Damospara	M/26	+	+	++	+	+	+	++	++	++	++	–	−	–	–

S = spotted, D = diffuse, Leu = leuco, WB = whole body, + = mild, ++ = moderate, +++ = severe, − = not detected

Rahman *et al.* 2003) were not able to account for these factors, the actual number of people with arsenical skin lesions in the affected villages may be much lower than the expected value.

Although we had registered 679 arsenicosis patients with arsenical skin lesions from all 21 villages of Sagarpara GP, the villagers of some of the severely affected villages informed us that we had examined only 20–25% of the total population that had the arsenical skin lesions. The reasons for this are: (i) in villages, the affected people thought their disease was contagious and if other people become aware of their ailment, they would be socially isolated; (ii) young girls and women of conservative families did not want to be examined; (iii) people were frustrated and felt that there was no cure for their disease; (iv) people who were weak and suffering extensively did not want to travel long distances to come to our camp; and (v) normally we visited the villages during the day, when most of the men were working in the fields. However, we did not expect 20.6% of the total population of 24,419 to be suffering from arsenical skin lesions in the Sagarpara GP considering the points discussed above.

CONCLUSIONS

From the overall study of groundwater arsenic contamination and its health effect in Sagarpara, it appears that the magnitude of the calamity in this GP is severe. It was also revealed from our generated data that the population drinking arsenic contaminated water above $10\,\mu g\,l^{-1}$ was about 21,000 while those drinking above $50\,\mu g\,l^{-1}$ was 14,000. The study has further revealed that many people in this GP may not be showing arsenical skin lesions but the analyses of biological samples indicated that many might be sub-clinically affected. Cancer cases were increasing among those suffering from severe arsenical skin lesions. Children seemed more susceptible to arsenic poisoning but usually did not show arsenical skin lesions if under the age of 11. Thus a new generation could be at risk. Since at present

Table 6 | Probable estimation of population that may suffer from arsenical skin lesions and cancer in Sagarpara comparing with international data

Study (author/ year)	Country/region	Health effect studied	No. of cases expected for Sagarpara	No. of cases expected for Sagarpara per 1,000
Astolfi *et al.* (1981)	Cordoba, Argentina	Regular intake of drinking water containing above 100 $\mu g\,l^{-1}$ of arsenic leads to clearly recognizable signs of arsenic toxicity and ultimately in some cases to skin cancer	11,000	458
Tsuda *et al.* (1995)	Nigata, Japan	Exposure for 5 years to a high dose of arsenic ($>$ 100 $\mu g\,l^{-1}$) can cause skin signs of chronic arsenicism and subsequent cancer development	11,000	458
USEPA (1992) NRC (1999)	–	Chronic intake of 10 $\mu g\,kg^{-1}$ arsenic per day or higher may result in dermatological and other sign of arsenic toxicity. An intake of 10 $\mu g\,kg^{-1}$ per day is equivalent to 125 $\mu g\,l^{-1}$ of arsenic in tubewell water on the basis of our field study, average 50 kg body weight for adults and 4 l of water consumption per day (Chowdhury *et al.* 2001).	10,000	416
Chakraborty & Saha (1987)	West Bengal, India	The lowest arsenic concentration in drinking water that produced dermatosis was found to be 200 $\mu g\,l^{-1}$	8,500	354
Oshikawa (1998)	Thailand	The prevalence of arsenic dermatosis in areas with 200 $\mu g\,l^{-1}$ of arsenic in drinking water	8,500	354
WHO (1981)	–	Several years of exposure of approximately 1,000 μg of arsenic per day may cause skin effects within just a few years. In arsenic affected areas of West Bengal, adults drink an average 4 l of water per day (Chowdhury *et al.* 2001). So 1,000 μg of arsenic per day is equivalent to 4 l of 250 $\mu g\,l^{-1}$ of arsenic containing water.	7,200	300
Morales *et al.* (2000)	Taiwan	The lifetime risk of death is 1 in 100 from consuming 50 $\mu g\,l^{-1}$ of arsenic in drinking water	143	6
NRC (2001)	–	Cancer mortality risks are about 1 in 100 at 50 $\mu g\,l^{-1}$ of arsenic	143	6
Smith *et al.* (1992, 2002)	Chile	Lifetime risk of dying from cancer while drinking 1 l of water per day with 50 $\mu g\,l^{-1}$ of arsenic is 13 in 1,000	186*	8
Smith *et al.* (1999)	Chile	Lifetime risk of dying from cancer while drinking 1 l of water per day with 500 $\mu g\,l^{-1}$ of arsenic is 13 in 100	415*	17
Chakraborti *et al.* (2002)	West Bengal, India and Bangladesh	Ingestion of 300 $\mu g\,l^{-1}$ of arsenic in drinking water for a couple of years may cause arsenical skin lesions	6,400	266

*Since in arsenic affected areas of West Bengal, adults drink an average 4 l of water per day (Chowdhury *et al.* 2001), we expect the numbers of patients to be four times higher there is almost no medicine for chronic arsenic poisoning, scientists all over the world should consider the issue a major challenge and find a way to save the affected population.

West Bengal is known as a land of rivers and available wetland is about 4,000 km^2 with flooded river basins and ox-bow lakes. The state also receives an average annual rainfall of about 1,600 mm. The Murshidabad district too has plenty of available surface water. Also, instead of using underground water, the state of West Bengal should focus on harvesting surface water. Alternative safe water sources such as dugwells and rainwater harvesting with controls for bacterial and other chemical contamination also need to be implemented. Careful watershed management that ensures the villagers' participation is the only way to combat the present arsenic crisis.

ACKNOWLEDGEMENTS

The authors thank the field workers from the School of Environmental Studies (SOES), Jadavpur University, for their extensive help in the field survey in Sagarpara GP. The authors wish to thank all the villagers of Sagarpara for their participation and assistance. Financial support from SOES is gratefully acknowledged.

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