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SPECIAL ISSUE

Groundwater arsenic contamination in Ganga–Meghna–Brahmaputra plain, its health effects and an approach for mitigation

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Abstract The authors' survey of the Ganga–Meghna–Brahmaputra (GMB) plain (area 569,749 km^2; population >500 million) over the past 20 years and analysis of more than 220,000 hand tube-well water samples revealed groundwater arsenic contamination in the floodplains of the Ganga–Brahmaputra river (Uttar Pradesh, Bihar, Jharkhand, West Bengal, and Assam) in India and the Padma–Meghna–Brahmaputra river in Bangladesh. On average, 50 % of the water samples contain arsenic above the World Health Organization guideline value of 10 μg/L in India and Bangladesh. More than 100 million people in the GMB plain are potentially at risk. The authors' medical team screened around 155,000 people from the affected villages and registered 16,000 patients with different types of arsenical skin lesions. Arsenic neuropathy and adverse pregnancy outcomes have been recorded. Infants and children drinking arsenic-contaminated water are believed to be at high risk. About 45,000 biological samples analyzed from arsenic-affected villages of the GMB plain revealed an elevated level of arsenic present in patients as well as non-patients, indicating that many are sub-clinically affected. In West Bengal and Bangladesh, there are huge surface water in rivers, wetlands, and flooded river basins. In the arsenic-affected GMB plain, the crisis is not over water scarcity but about managing the available water resources.

Keywords Groundwater arsenic contamination in GMB plain · Adverse health effects · Sub-clinical effects of arsenic · Arsenic and children · Source of arsenic · Mitigation options

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Introduction

Based on the authors' survey over the past 20 years of the Ganga–Meghna–Brahmaputra (GMB) plain (an area of 569,749 km^2, with a population of over 500 million), it was predicted that some portions of all the states in the Ganga–Brahmaputra plain in India (Uttar Pradesh, Bihar, Jharkhand, West Bengal, Arunachal Pradesh, Assam), six out of seven North Eastern Hill states in India (except the state of Mizoram) and the Padma–Meghna–Brahmaputra (PMB) plain in Bangladesh are adversely affected by arsenic-contaminated groundwater (Chakraborti et al. 2004). In 1976, groundwater arsenic contamination in Chandigarh and some areas in Punjab in North India was reported (Datta and Kaur 1976). In 1984, groundwater arsenic contamination in the lower Ganga plain of West Bengal was first reported (Garai et al. 1984). In 1992, arsenic groundwater contamination was identified in the PMB plain of Bangladesh (Dhar et al. 1997). The issue of the adverse effects of arsenic contamination in West Bengal received much attention only after the International Conference at Kolkata in 1995. The issue was brought to the notice of the government and aid agencies in Bangladesh; however, they were reluctant to acknowledge the seriousness of the situation. Therefore, another international conference at Dhaka was organized in collaboration with the Dhaka Community Hospital (DCH) to highlight that Bangladesh was the worst affected by arsenic contamination. A total of 50 patients were made to be present at the conference. In 2001, groundwater arsenic contamination in the Terai region of Nepal was revealed (Shrestha et al. 2003). In June 2002, arsenic contamination in Bihar in the middle Ganga plain was discovered and contamination identified in Uttar Pradesh in the middle and upper Ganga plain (Chakraborti et al. 2003). During October–December 2003, December 2003–January 2004, and January–February 2004, arsenic contamination and its adverse health effects in Uttar Pradesh, Jharkhand, and Assam states in India, respectively were discovered (Chakraborti et al. 2004; Ahamed et al. 2006a). During May 2006, a preliminary survey in Manipur, one of the seven North Eastern Hill states of India, was conducted. Hand tube wells usually exist in the plain land of Manipur. The plain land of Manipur comprises 8 % of the total area of Manipur and 60 % of the population of Manipur live in this plain land (Chakraborti et al. 2008, 2009). Despite that the research was conducted for over 20 years in the GMB-plain, the authors prefer to call it a preliminary study. This is because of the authors' strong belief from the field survey that the problem is much larger than it appears. Even today with authors' every new field survey, new arsenic-affected villages where people are not aware that they are drinking arsenic-contaminated water and that their skin lesion is due to arsenic toxicity were identified. Figure 1 shows the presence of arsenic-contaminated groundwater (>50 μg/L) in districts in states of India and Bangladesh in GMB-plain and also shows the areas in GMB-plain potentially at risk from groundwater arsenic contamination, including seven North Eastern Hill states.

This communication deals with the present groundwater arsenic contamination situation in GMB-plain, its health effects, and an approach for mitigation on the basis of the authors' past 20 years of research work on the issue.

Groundwater arsenic contamination in Bangladesh

In collaboration with the DCH, Bangladesh, so far hand tube-well water samples from 3,600 villages out of approximately 68,000 villages in Bangladesh (an area of 147,620 km^2 with a population of about 130 million) have been collected. Arsenic concentration in 2,500 of these villages was found to be above 10 μg/L (the WHO recommended level of arsenic in drinking water) and above 50 μg/L (the recommended level of arsenic in drinking water in Bangladesh) in 2,000 villages. Water samples have been collected from all 64 districts in Bangladesh. Based on the analysis of 51,000 water samples, 40.3 % of hand tube wells have arsenic contamination of above 10 μg/L; 26.3 % above 50 μg/L; and 7.1 % above 300 μg/L.

Of the 64 districts, groundwater arsenic contamination was found to be above 10 μg/L in 60 districts and above 50 μg/L in 51 districts. The area and population of the affected 51 districts are 121,145 km^2 (82 % of the total area of Bangladesh) and 113 million (87 % of the total population of Bangladesh), respectively. The arsenic concentration of the hand tube-well water sample from Chiladi village of Senbag upazila in the Noakhali district was found to be 4,730 μg/L. This was the highest arsenic concentration level that the authors have ever observed in over a 20-year study. The medical team has hitherto screened 18,841 individuals and registered 3,762 individuals (adults 3,464; children 298) as arsenicosis patients with clinical manifestation. Figure 2 shows the arsenic-contaminated and uncontaminated districts in Bangladesh.

Groundwater arsenic contamination in the state West-Bengal, India

In the Past 20 years of study, 140,150 hand tube-well water samples have been analyzed for arsenic in all 19 districts of West Bengal. Out of 140,150 samples analyzed for arsenic to date, 48.1 % had arsenic above 10 μg/L and 23.8 % above 50 μg/L. Importantly, 3.3 % of the analyzed tube wells had arsenic concentrations above 300 μg/L, the concentration

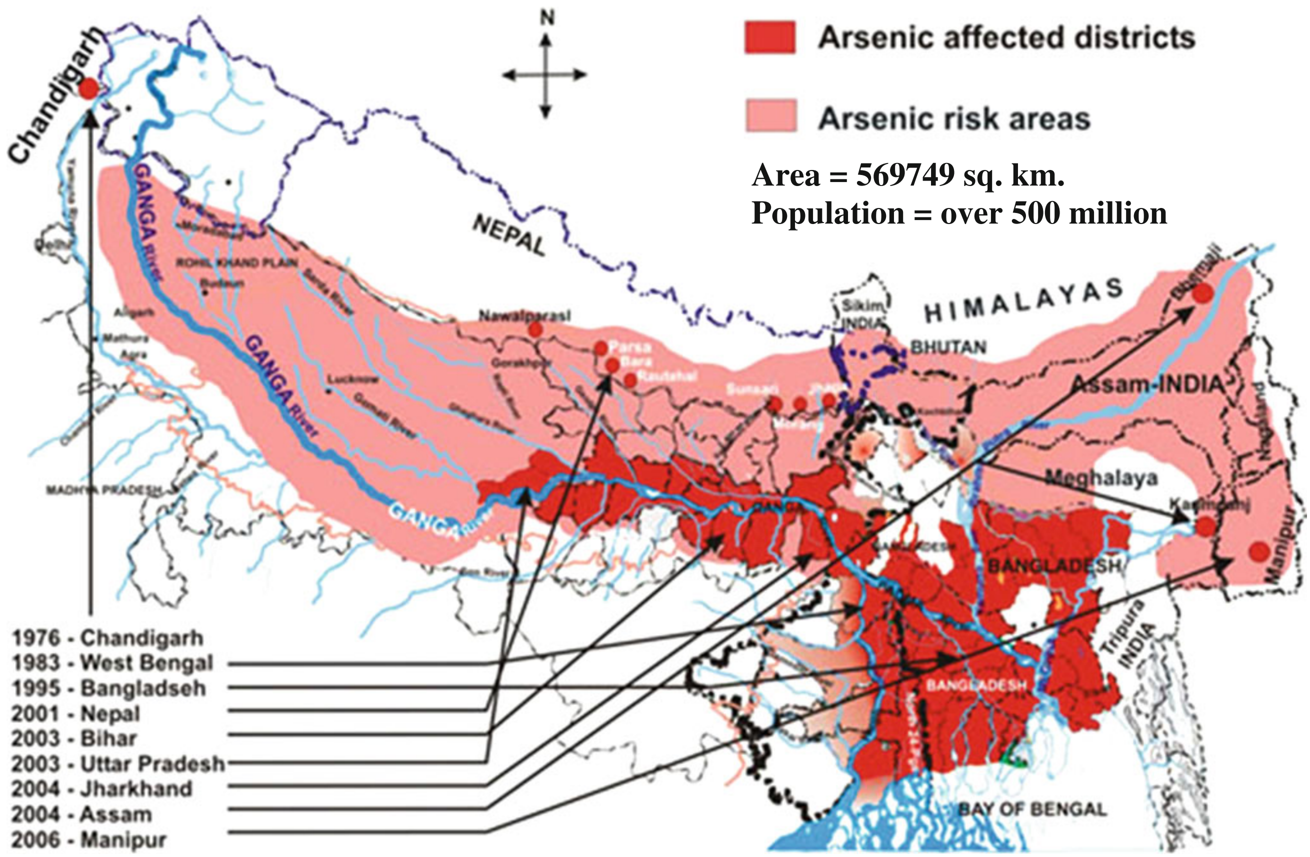

Fig. 1 Arsenic-affected areas of Ganga–Meghna–Brahmaputra (GMB) plain

predicting overt arsenical skin lesions (Rahman et al. 2001). A total of 187 (0.13 %) hand tube wells were determined as highly contaminated (>1,000 µg/L). The maximum arsenic concentration (3,700 µg/L) was found in Ramnagar village of Gram Panchayet (GP) Ramnagar II, Baruipur block, in South 24 Parganas district. This tube well was a private one and all the nine members of the owners' family had arsenical skin lesions and seven of them who had severe arsenical skin lesions had already died ; five of them within the age range below 30 years died . Figure 3 shows the groundwater arsenic contamination status of all 19 districts of West Bengal. Based on the arsenic concentrations found in the 19 districts of West Bengal, they have been classified into three categories: severely affected, mildly affected, and unaffected. Nine districts (Malda, Murshidabad, Nadia, North 24-Parganas, South 24-Parganas, Bardhaman, Howrah, Hooghly, and Kolkata), where more than 300 µg/L arsenic concentrations were found in tube wells, are categorized as severely affected. Out of 135,555 samples analyzed from these districts 67,306 (49.7 %) had arsenic concentrations above 10 µg/L and 33,470 (24.7 %) above 50 µg/L. The five districts (Kooch Bihar, Jalpaiguri, Darjeeling, North Dinajpur, and South Dinajpur) showing concentrations mostly below 50 µg/L (only a few above 50 µg/L but none above 100 µg/L), are termed as mildly affected. The authors analyzed 2,923 water samples from these districts; 285 (9.8 %) had arsenic concentration between 3 and 10 µg/L; 163 (5.7 %) above 10 µg/L; and 6 (0.2 %) above 50 µg/L.

The other five districts (Bankura, Birbhum, Purulia, Midnapore East, and Midnapore West) are unaffected or arsenic safe. All the samples ($n = 1672$) had arsenic concentrations below 3 µg/L (the minimum determination limit of the FI-HG-AAS instrument with 95 % confidence level). The medical team has hitherto screened 96,000 individuals (adults 82,000; children 14,000) from seven arsenic-affected districts and registered 9,356 [adults 8,578 (10.5 %); children 778 (5.6 %)] as arsenicosis patients with clinical manifestations.

Groundwater arsenic contamination in the state of Bihar, India

The state of Bihar consists of 37 districts. Its population and area are 83 million and 94,163 km^2, respectively. In the authors' study since 2002, 19,961 hand tube-well water samples were analyzed from 12 districts and arsenic concentration was found in all of the 12 districts to be above

Fig. 2 Arsenic-contaminated and uncontaminated districts in Bangladesh

50 μg/L. Arsenic concentration above 10 μg/L (WHO recommended level of arsenic in drinking water) was also found in 313 villages and above 50 μg/L in 240 villages. The area and population of the affected 12 districts are 21,432 km^2 (22.76 % of the total area of Bihar) and 27.64 million (33.35 % of the total population of Bihar), respectively. These analytical results show that 32.7 % of the tube wells had arsenic concentration of over 10 μg/L; 17.75 % above 50 μg/L, and 4.55 % above 300 μg/L. The maximum arsenic concentration of 2,182 μg/L was found in the Chakani village of Gram Panchayet Brahampur, Barahara block in Buxar district. In the preliminary survey, 3,012 individuals from highly contaminated villages (adults 2,124; children 888) were hitherto screened and 457 were registered (adults 396–18.64 %, children 61–6.87 %) as arsenicosis patients with clinical manifestation. Figure 4 shows the groundwater arsenic-contaminated areas that have been identified so far in Bihar. From the preliminary findings, it is also expected that arsenic contamination in districts of Bihar are close to the arsenic affected Terai region of Nepal.

Groundwater arsenic contamination in the state of Uttar Pradesh (UP), India

The area and population of UP situated in the upper and middle Ganga plain are 238,000 km^2 and 166 million, respectively. The state of UP consists of 70 districts. The authors identified groundwater arsenic contamination in UP in 2003 (Chakraborti et al. 2003). Analyses of 4,780 tube-well water samples from the three districts of Ballia, Varanasi, and Gazipur in the upper and middle Ganga plain revealed that arsenic concentration exceeded 10 μg/L in 45.48 %; 50 μg/L in 26.51 %; and 300 μg/L in 10.0 %. The area and population of the three affected districts are 11,450 km^2 (4.8 % of the total area of UP) and 8.7 million, approximately (5.3 % of the total population of UP). The maximum arsenic concentration of 3,191 μg/L was found in the Hansnagar village of Gram Panchayet, Belhari block, Ballia district. The medical team has hitherto screened 989 individuals from villages (adults 634, children 355) and registered 154 (adults 137–21.6 %, children 17–4.79 %) as arsenicosis patients with clinical manifestations. Figure 5 shows the arsenic-contaminated districts so far that have been identified in UP. This is a very preliminary report in UP. More arsenic-contaminated districts are expected as well as in districts of UP close to Nepal like Bihar state.

Groundwater arsenic contamination in the state of Jharkhand, India

The state of Jharkhand consists of 22 districts. Its area and population are 75,834 km^2 and 27 million, respectively. From December 2003 to date, nine blocks of Sahibganj district in the middle Ganga plain were surveyed; three of them were determined to be arsenic contaminated (Chakraborti et al. 2004). From Sahibganj districts of Jharkhand, 3,832 hand tube-well water samples were analyzed for arsenic: arsenic concentration of above 10 μg/L in 32.28 % of the samples, above 50 μg/L in 13.44 %, and above 300 μg/L in 2.61 % were found. The area and population of Sahibganj district are 3,405 km^2 (4.5 % of the total area of Jharkhand) and 1 million, approximately (3.7 % of the total population of Jharkhand). The maximum arsenic concentration of 1,018 μg/L was found in the Hajipur Vitta village of Hajipur Porsun Gram Panchayet, Sahibganj block, Sahibganj district of Jharkhand. The medical team screened 562 individuals from arsenic-affected villages (adults 522, children 40) and registered 71 (adults 64–12.26 %, children 7–17.5 %) as arsenicosis patients with clinical manifestations. Figure 6 shows the arsenic contamination situation in Jharkhand state.

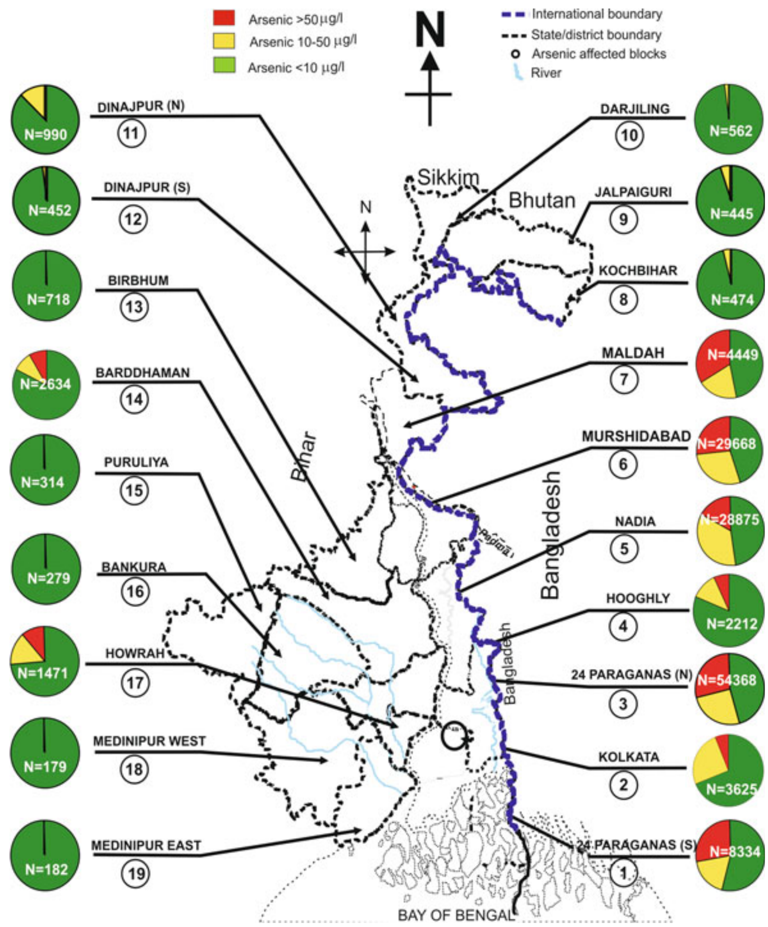

Fig. 3 Groundwater arsenic contamination status of all 19 districts in West Bengal, India

Fig. 4 Groundwater arsenic-contaminated areas so far we have identified in Bihar

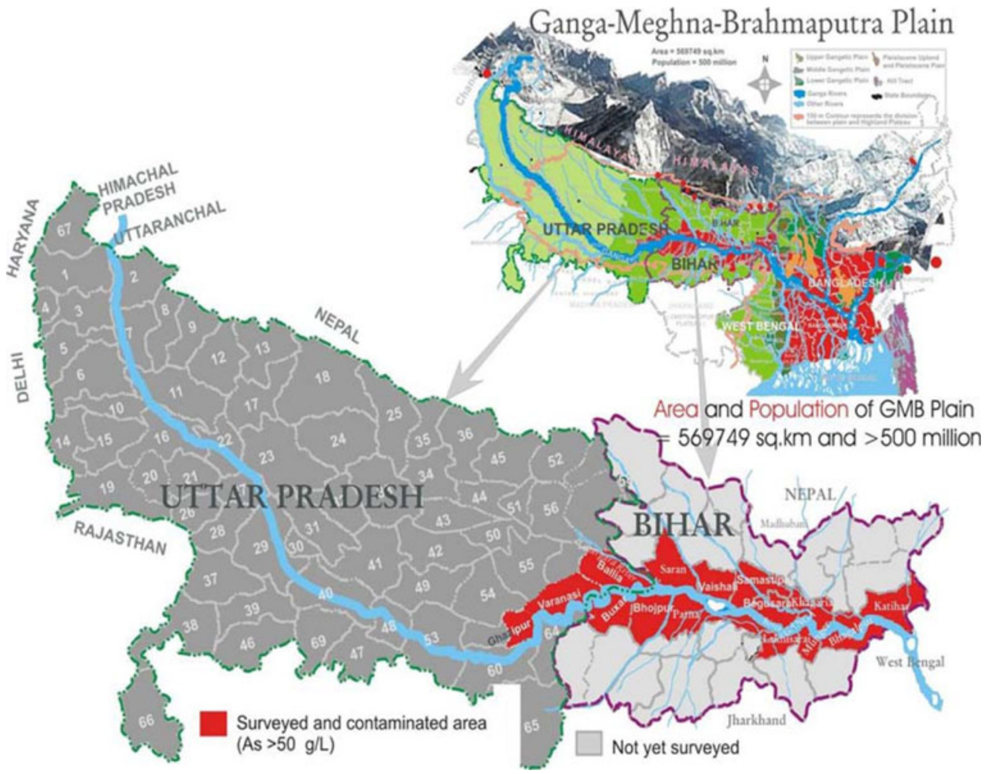

Fig. 5 Arsenic-contaminated districts so far we have identified in UP and Bihar

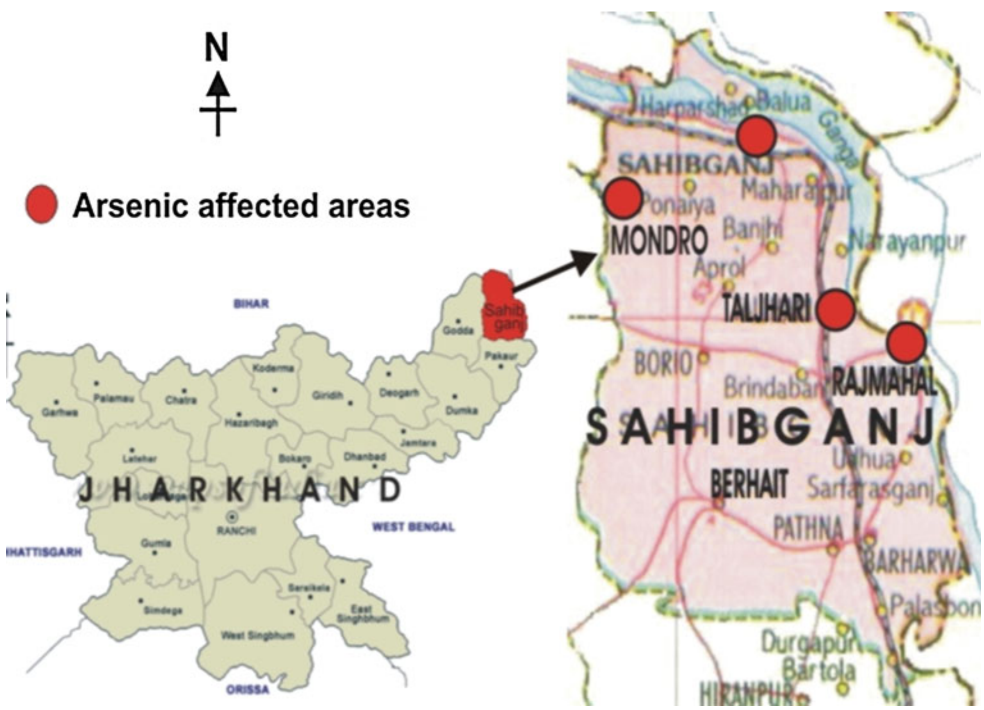

Fig. 6 Arsenic-contaminated districts identified so far in Jharkhand

Groundwater arsenic contamination in the North-Eastern Hill states, India

The total area and population of the seven North-Eastern Hill states (Manipur, Tripura, Assam, Meghalaya, Nagaland, Mizoram and Arunachal Pradesh) of India are 2,51,699 km^2 and 35.8 million, respectively. In January 2004, arsenic contamination was detected in the groundwater of the upper Brahmaputra plain in Assam (Chakraborti et al. 2004). From Dhemaji and Karimganj districts of Assam, 241 hand tube-well water samples were analyzed; 42.3 % of the samples contained arsenic above

10 μg/L; and 19.1 % above 50 μg/L. Groundwater arsenic contamination is also expected in the other North-Eastern Hill states.

Manipur The source of arsenic in GMB plain is the Himalayas and the surrounding mountains. The North-Eastern Hill states were formed at a late phase of Himalayan orogeny. Thus, groundwater arsenic contamination is also expected in the flood plains of North-Eastern Hill states as well as in the flood plain of the country Bhutan. The authors found that the groundwater in Manipur, one of the seven North-Eastern Hill states in India, is also affected by high arsenic concentration (Chakraborti et al. 2008). The total area of Manipur is 22,327 km^2, and its population is 2.39 million. It has nine districts out of which four districts, namely, Imphal East, Imphal West, Thoubal, and Bishnupur, are in the plain land and are together known as Manipur Valley. The other five districts are in hilly areas. Manipur Valley constitutes only 10 % of the total area of the state. However, 60 % of the population of the state lives in the Manipur Valley. All the four districts in the Manipur Valley are arsenic contaminated. Water samples from 628 of the total of 2,014 hand tube wells, both public and private were analyzed. About 63.3 % of the total sample size showed arsenic contamination of >10 μg/L, 23.2 % between 10 and 50 μg/L; and 40 % above 50 μg/L. The percentage of contamination above the WHO guideline value of arsenic in drinking water (10 μg/L) and Indian Standard (50 μg/L) in Manipur was higher than other arsenic-contaminated states and countries in the GMB Plains. The total number of public and private tubewells in the Manipur Valley have been estimated and the distribution of arsenic in all of the four districts of the valley reported. The number of users of each tube well was also studied. The arsenic concentration with the depth of the tube well was compared as well as the concentration of arsenic with that of iron in the tube-well water. The level of arsenic in urine was tested to evaluate the degree of exposure of the population of the Manipur Valley. A comparative study of arsenic-related parameters from the Manipur Valley with other arsenic-affected states and countries in the GMB plains was also conducted. Manipur Valley is subdivided into older and newer Alluvium deposits. The newer Alluvium is mainly composed of clay, sand, silt, and dark clay with carbonaceous matter. It is deposited mainly in the central and upper part of the Manipur Valley. Arsenic-contaminated aquifers are mainly confined within this Newer Alluvium. Groundwater arsenic contamination in the valley areas of other North-Eastern Hill states is also expected. At present, there is no widespread use of tube-well water in the Manipur Valley. In fact, the field survey shows that the villagers do not like the taste of tube-well water. This is similar to the scenario in West Bengal and Bangladesh four decades ago. There are plenty of available resources of surface water and rainwater in Manipur. The authors recommended that the state should avoid use of its underground water and thus protect itself from the risk of arsenic toxicity faced by the rest of the GMB plain. Figure 7 shows the North-Eastern Hill states and arsenic-affected areas in Manipur state.

Clinical effects of groundwater arsenic contamination in the GMB plain and arsenical skin lesions (permission taken from the arsenic patients for their photographs)

The symptoms of arsenical dermatosis were observed during field visits in affected areas of the GMB plain (Mandal et al. 1996; Rahman et al. 2001; Chakraborti et al. 2004; Mukherjee et al. 2005; Saha 2003). It was observed that drinking water with more than 300 μg/L arsenic for a couple of years could cause arsenical skin lesions (Chakraborti et al. 2002). However, nutrition and diet have a considerable influence on the prevalence of skin lesions. The medical group examined 96,000 individuals from nine arsenic-affected districts of West Bengal and 9,356 of them had arsenical skin lesions; 18,841 individuals were examined from 260 villages, 77 police stations, and 31 districts of Bangladesh. About 3,762 of them had skin lesions. In the preliminary survey, the medical team examined 3,012 individuals from 17 villages, 7 blocks and 6 districts in Bihar. About 457 of them had skin lesions. The medical team has so far examined 989 individuals from 2 districts of Uttar Pradesh of whom 154 had arsenical skin lesions. In Jharkhand, 562 people were screened from the Sahibganj district and 71 of them were found to have arsenical skin lesions, including cases of skin cancer. Figure 8 shows various types of arsenical skin lesions common to those suffering from arsenic toxicity. According to toxicologists, these skin lesions are external manifestations of severe internal damage. Other than dermal effects arsenic may cause cardiovascular effects, respiratory effects, gastrointestinal effects, endocrinological effects, neurological effects, reproduction, and developmental effects. During the past 20 years of this survey in arsenic-affected areas, it was noted that those suffering from severe arsenical keratosis may develop skin cancer.

Figure 9 shows some of the skin cancer patients in arsenic-affected areas in GMB-plain. In recent years more information can be found (NRC 2001) of internal cancers for those suffering from arsenical skin lesions like lung, liver, lung cancer, liver cancer, urinary bladder and kidney cancer.

Arsenical neuropathy

Neurological examination was generally undertaken for arsenicosis patients whose skin lesions were already

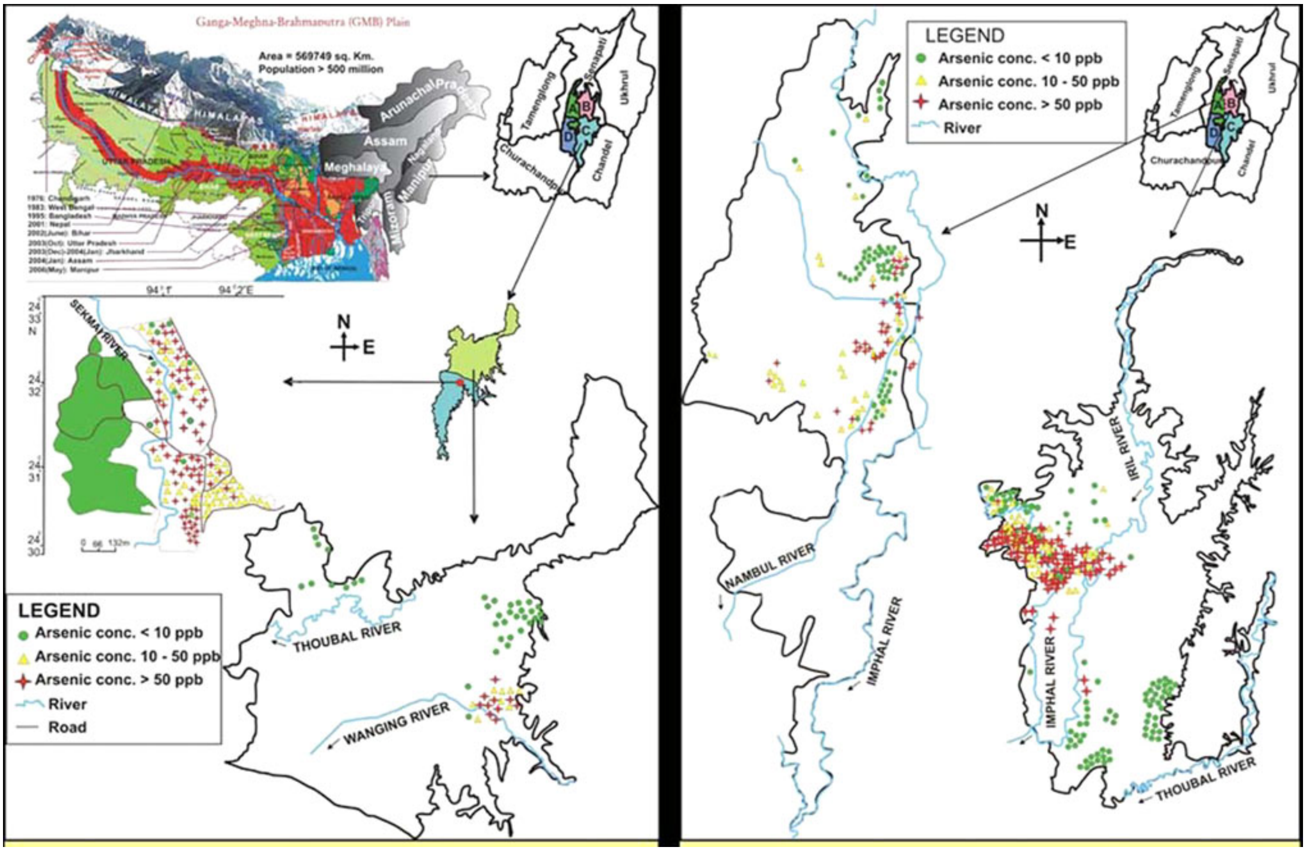

Fig. 7 Groundwater arsenic contamination status in the North-Eastern Hill states and arsenic-affected areas in Manipur state (Chakraborti et al. 2008)

diagnosed by an experienced dermatologist. The neurological part was conducted by an experienced neurologist to obviate inter-observer variability for each patient of arsenicosis so tested. Observations were recorded for items considered consistent with peripheral motor and sensory neuropathy and for other neurological abnormalities as well. There was emphasis on pain history and pain-specific sensory examination (Mukherjee et al. 2003, 2005). The items included to characterize neuropathy were (1) pain and paraesthesias (e.g., burning) in a stocking and glove distribution, (2) numbness, (3) hyperpathia/allodynia, (4) distal hypesthesias (reduced perception of sensation to pinprick/reduced or absent vibratory perception/affected joint-position sensation/affected touch sensation), (5) calf tenderness, (6) weakness/atrophy of distal limb muscles or gait disorder, and (7) reduction or absence of tendon reflexes. These studies observed an overall prevalence of clinical neuropathy based on previously defined criteria (Rahman et al. 2001; Feldman et al. 1979; Galer 1998). About 980 individuals underwent detailed neurological examination and about 471 were registered from the Murshidabad and Nadia districts of West Bengal, Bhojpur district of Bihar, Ballia and Gazipur districts of UP, India, and Comilla district of Bangladesh (Rahman et al. 2001; Mukherjee et al. 2003, 2005; Chakraborti et al. 2003, 2004; Ahamed et al. 2006a, b).

Arsenic in drinking water and obstetric outcome

Arsenic exposure during pregnancy can adversely affect several reproductive endpoints. In several studies, the association between arsenic exposure and adverse pregnancy outcomes were investigated, including spontaneous abortion, pre-term birth, stillbirth, low birth weight, and neonatal and perinatal mortality (Chakraborti et al. 2003, 2004). All these parameters were compared with those observed in the unexposed women group from a non-arsenic exposed district (Medinipur) of West Bengal. Adverse obstetric effects were observed in around 56 adult women from the Murshidabad district, West Bengal (Chakraborti et al. 2004; Mukherjee et al. 2005); Bhojpur district of Bihar (Chakraborti et al. 2003); Ballia district of UP (Ahamed et al. 2006a); and Comilla district, Bangladesh (Ahamed et al. 2006b).

The study from Taiwan also reported a slightly high rate of pre-term birth (Yang et al. 2003) in an exposed population. In the previous study in Bihar (Chakraborti et al. 2003) and West Bengal (Chakraborti et al. 2004), pre-term birth

Fig. 8 Various types of arsenical skin lesions prevalence in those suffering from arsenic toxicity

was noted to be higher. An extensive study (Yang et al. 2003) provided evidence of low birth weight. Spontaneous abortion was previously cited in several studies (Nordstrom et al. 1979; Ahmad et al. 2001; Aschengrau et al. 1989). High still-birth rate was observed in many studies (Ahmad et al. 2001; Yang et al. 2003). Low birth weight was also a notable feature in many studies (Ahmad et al. 2001).

Subclinical effects of arsenic

Arsenic concentration in hair, nail, and urine plays an important role in evaluating the arsenic body burden (NRC 1993). From arsenic-affected regions of West Bengal, 40,000 biological samples (urine, hair, and nail; including 1,000 skin scales); 10,000 from Bangladesh; 1,883 from Bihar; 258 from Uttar Pradesh; and 367 from Jharkhand were analyzed. During the survey in the arsenic-affected villages of Bihar, UP, and Jharkhand, a high level of arsenic present in the urine samples from both patients and non-patients was observed. This indicated that they were drinking contaminated water (Chakraborti et al. 2003, 2004). Hair, nail, and urine samples were analyzed from both patients and non-patients in the same village. About 30–40 % of hair, nail, urine, and skin scales were collected from patients and the remainders were from non-patients. From the analysis of biological samples from the GMB plain, it is understood that many villagers may not be affected by arsenical skin lesions, but have elevated levels of arsenic in their hair and nails, and thus may be sub-clinically affected. The elevated arsenic concentrations in urine demonstrate that most of the villagers were drinking contaminated water (current exposure) (see Table 1).

The effect of arsenic poisoning in children

Infants and children are often considered more susceptible to the adverse effects of toxic substances than adults (NRC 1993).

Fig. 9 Some of the skin cancer patients in arsenic-affected areas in GMB-plain

Table 1 Statistical representation of arsenic in biological samples from West Bengal, India and Bangladesh

Parameters	West Bengal				Bangladesh			
	As in hair[a] (μg/kg)	As in nail[b] (μg/kg)	As in urine[c] (μg/L)	As in skin scale[d] (μg/kg)	As in hair[a] (μg/kg)	As in nail[b] (μg/kg)	As in urine[c] (μg/L)	As in skin scale[d] (μg/kg)
No. of observations	8,400	8,665	11,000	230	4,536	4,471	1,586	705
Mean	1,480	4,560	180	6,820	3,390	8,570	280	5,730
Median	1,320	3,870	115	4,460	2,340	6,400	115.78	4,800
Minimum	180	380	10	1,280	280	260	24	600
Maximum	20,340	44,890	3,147	15,510	28,060	79,490	3,086	53,390
Standard deviation	1,550	3,980	268	4,750	3,330	7,630	410	9,790
% of samples having arsenic above normal/toxic level (hair)	62	84	89	–	83	93	95	–

[a] Normal level of arsenic in hair ranges from 80 to 250 μg/kg; 1,000 μg/kg is the indication of toxicity

[b] Normal level of arsenic in nail ranges from 430 to 1,080 μg/kg

[c] Normal excretion of arsenic in urine ranges from 5 to 40 μg/1.5 l (per day)

[d] There is no normal value of arsenic for skin scales in literature

Normally, children under 11 years of age do not show arsenical skin lesions although their biological samples contain high level of arsenic. However, exceptions were observed as when (1) arsenic content in water consumed by children is very high (≥1,000 μg/L) and (2) arsenic content in drinking water is not so high (around 500 μg/L), but the children's nutrition is poor (Chowdhury et al. 2000). High arsenic content in their biological samples prove that children in the arsenic-affected areas of the GMB plain have a higher body burden, though dermatological manifestations are few (Chakraborti et al. 2004 and refernces therein).

The children in the arsenic-contaminated areas are often more affected than the adults. Children's bodies try very hard to expel the poison from their systems; however, in trying to do so their internal organs become badly damaged, which, in turn, retards their further growth, both physically and mentally. The future generation is in dire danger. Unimaginable sufferings of children have been witnessed by authors in arsenic-affected areas in GMB plain.

The authors visited Madanpur village in the Bhagabangola block in Murshidabad district, in February 1992. The area did not even have a proper road then. For more than 6 km authors walked through agricultural fields to reach the village, where it was found that the villagers did not know about the arsenic contamination in tube-well water and its health effects. An old man introduced his daughter-in-law, who had been the village beauty and had become skin and bones in just 5 years. Her skin was covered in lesions. Among the 300 villagers, about 150 had the symptoms of arsenic poisoning; 40 % of the children between 6 and 11 years suffering from malnutrition had the symptoms visible on their skin (Fig. 10). The authors had never seen so many children affected in one spot anywhere before, and it was painful to think of their fate. Photographs of these children are included in the publication of post international arsenic conference report (Post Conference Report 1995), to indicate the danger for future generations. The three tube wells that the villagers of Madanpur used for drinking purposes had an average arsenic level of 700 μg/L. They believed the disease visited them as a punishment of their previous births' sins or the gods' curses. The authors attempted to make them understand that it came from drinking of contaminated water and that arsenic-free water and seasonal fruits and vegetables were the only remedy. A diet of fish, meat, eggs, and milk helps fight this disease; however, the villagers living below poverty line could not indulge in such luxuries.

Fig. 10 Some arsenic-affected children having arsenical skin lesions

The authors tried to convince them that seasonal fresh fruits, vegetables, and pulses, etc., would be as efficient as a high-protein diet. They were asked to obtain their drinking water from the neighboring village which had safe tube wells. They refused point blank, saying it was too far. The matter was reported to the government, but to no avail. Over time, Madanpur village slipped from authors mind.

Ten years later, again in February, 2002, the authors went to conduct a survey in Najirpur village of the same Bhagabangola block. As the villagers spoke of Madanpur, the authors were reminded of the fateful day 10 years ago and also of the condition of the road. Villagers told authors the road was now better and authors could go close to the village by car; therefore, the authors decided to visit Madanpur again. Nothing had changed in the village during the past 10 years: the same mud houses with straw roofs on uplands for safety from flood, bamboo bushes, dirty small water bodies, the breeding ground for mosquito. Surprisingly, it seemed that bare-footed half-naked, the same affected children from 10 years before were surrounding the authors once again. It was as if they had not aged in the past 10 years. The authors asked for the old man and his daughter-in-law. The man was dead. The daughter-in-law could recognize us. She was not more than 30 years old, but looked like she was 60. When the children whom the authors had seen 10 years ago were asked for, some had died, some had gone to work, and others who had lost their strength, were at home. She called them. The young adults that came and stood before us now looked like live but bloodless skeletons. It was apparent from the children who were present that the threat of arsenic was still alive and arsenic tradition was continuing. Figure 11 shows an 18-month-old child from Bangladesh with arsenical keratosis. It is probably the youngest child in the world to have arsenical skin lesions.

Source and mechanism of arsenic contamination

From the arsenic contamination scenario in Asia, it appears that the flood plains of many rivers originating from the

Fig. 11 An 18-month-old child from Bangladesh having arsenical keratosis

Himalayan Mountains and the Tibetan plateau are affected (Chakraborti et al. 2004). On this basis, arsenic contamination was noticed in West Bengal, Bihar, Jharkhand, UP in the Gangetic plain, Brahmaputra plain in Assam, and PMB plain in Bangladesh. The source is geologic. Various theories have been postulated on sources of arsenic and mechanism of mobilization from the source (Bhattacharya et al. 1997; Nickson et al. 1998; Roy Chowdhury et al. 1999; Harvey et al. 2002; Islam et al. 2004). The exact nature of mobilization process is still unknown.

An approach to combat the groundwater arsenic contamination problem

This is a bad situation as regards the arsenic contamination in drinking water and its health effects in GMB-plain. The authors have traveled extensively over the past 20 years in the states of India and Bangladesh that have been affected by arsenic, and have spoken to governmental and non-governmental officials as well as common people in the villages, and have come up with some ideas to combat the arsenic problem.

1. Water samples from more than 220,000 tube wells in the arsenic-affected GMB plain with FI-HG-AAS have been tested. The results show that in 25 % of the total samples the level of arsenic contamination is above 50 μg/L (permissible level of arsenic in drinking water of India and Bangladesh is 50 μg/L), and in 45 % of the total samples the level of arsenic contamination is 10 μg/L above the WHO guideline value of arsenic in water. Almost every village has some tube wells with arsenic safe water. If the level of arsenic contamination in the water of each of these tube wells is properly analyzed, and the tube wells marked 'safe' (say, in green paint) and 'unsafe' (in red paint), then it will be possible to have arsenic-free water, at least temporarily. The 'safe' tube wells need to be checked every 6 months to see whether the water is still free from contamination. Innumerable people continue to drink contaminated water because (a) there is a lack of proper planning, (b) there is a lack of awareness about the effects of arsenic contamination in the villagers, and (c) there is a lack of proper testing of the water from the tube wells. Apart from that, village doctors and most of the city doctors cannot identify symptoms of arsenic poisoning. The following two examples prove the above assertion:

A. It is known to the state government as well as to the district officials of Nadia that all 17 blocks of Nadia district are prone to arsenic contamination (Chakraborti et al. 2009). Water from the tube wells needs to be tested for arsenic before drinking, but is not. As a result, thousands of villagers drink contaminated water every day.

Balaram Biswas is an inhabitant of Kanainagar village, Tehatta-1 block, Nadia (40-year-old now); he has been ailing for the past 6–7 years, and we had admitted him to the Calcutta Medical College (22 January 2007) for treatment. His body is speckled with dark spots, and the palms of his hands and the soles of his feet are hard and granular. He has all the symptoms of an arsenic-induced disease, yet none of the doctors who did a check-up on him proclaimed him to be an arsenic patient. He has been meeting the expenses of his treatment by selling off his lands bit by bit. The water from the tube wells of that village were tested in December 2006 and it was found that Balaram Biswas' tube well had 576 μg/L of water, i.e., 57 times more than the stipulated amount of 10 μg/L as declared by the WHO. 50 % of the water in this village was fit for drinking. The authors bought red and green paint and gave it to a headman of the village, requesting him to paint the tube wells as necessary, citing Balaram Biswas' case as an example. If the horror of the arsenic problem could be shown to the villagers, especially the women and children, on a big screen through video, then perhaps they would have understood the impact of the crisis. The authors do not know whether such an effort towards awareness has been undertaken in any of the villages of West Bengal yet.

B. Kartik Biswas is a graduate student of Geography in the Krishnanagar Government College in Nadia. For last 3 years, the authors are bearing the expenses of his education. His mother Dulali Biswas was undergoing treatment for cancer at the Calcutta Medical College. She died at the age of 48 in October 2006. For 15 years she had the symptoms of arsenic toxicity on her skin. Towards the end, she developed a sore on the palm of her hand, and part of her hand had to be amputated. After a few months, another sore developed on her hand, and this time her arm had to be amputated to the elbow. Ultimately, she could not be saved. Kartik's grandparents, parents, and uncle and aunt, all died within 35–45 years of age, and all had the symptoms of arsenic infection on their skins. All of them except his grandmother died of cancer. They suffered for two decades; however, until 2003 none of them knew that they were affected by arsenic-induced diseases. The authors were the first to tell them of the contamination in the tube wells; 17 out of the 30 tube wells in this village had an arsenic level of more than 50 μg/L of water. The tube well, from which Kartik's family used to get its drinking water, had been lifted up, so its level of contamination could not be determined. When the authors first saw Kartik, he had very faint arsenical skin lesions, which have faded over time.

Twenty-five years have passed since the arsenic contamination problem was first detected in West Bengal. Yet no more than three hospitals have the infrastructure to detect the symptoms of arsenic poisoning.

2. The government should immediately formulate a regulation that a tube well may not be set up without prior governmental permission, and enforce it. At present, the number of tube wells in West Bengal and Bangladesh is 3–4 and 8–10 million, respectively. More than 95 % of the population in rural West Bengal and Bangladesh use water from tube wells as drinking water. So much so that many families have two to three tube wells set up in the house. Farmers use tube-well water for irrigation in summer and even in the rainy season if there is not enough rain. A lot of water is wasted this way, as there is no rule or regulation regarding the drawing of groundwater.
3. Inhabitants of the GMB and other river flood plains had used for thousands of years the traditional sources of water like rivers, ponds, lakes, dug wells, and other water bodies for consumption. Even in the extreme southern part of Bangladesh rain water harvest is a traditional procedure for drinking water.

Mostly this water is naturally free from arsenic, but in the present situation, it remains to be seen whether this water is free from other harmful chemicals and bacteria. Modern science can very easily remove harmful chemicals and disinfect water. Therefore, if surface water is available it can be purified and used for drinking. During this survey in GMB plain it was noticed that there were hundreds of wet-lands, flooded river basins, and Ox-Bow lakes, dead river channels with plenty of water round the year and thousands of abandoned big diameter dug wells. According to villagers, once these dug wells were the only source of drinking water in the villages and the community managed it. Dug well culture died down due to cheap, easy availability, and wide use of hand tube wells.

4. Traditionally in years past, water was left overnight in a pot and passed through a sieve made of very fine cloth the next day before drinking. The authors have seen that this tube-well water has excessive amounts of iron in it, which, when the water is left overnight in this manner, dissolved iron precipitates as iron-oxy-hydroxide co-precipitating arsenic and settles at the bottom of the pot as a residue, along with the arsenic. Sieved simply by two layers of fine cloth, 70–80 % of the arsenic is left out. Awareness and education are all the villagers need.
5. No medication has been invented yet that can cure chronic arsenic toxicity. This problem can only be battled with arsenic-safe water, nutritious food, and physical exercise. What the villagers do not know is that West Bengal and Bangladesh grow many seasonal fruits and vegetables that have a high-nutrition value. Moreover, the nutrition value of food decreases when it is subjected to great heat and too much spice in an attempt to make it tastier. If food is cooked properly, the villagers will not have to depend on a high-protein diet.
6. A good portion of over 500 million inhabitants of the GMB belt are living in constant danger of being affected by arsenic contamination. Scientists, technologists, and doctors will have to unite to find a solution to this problem. Civilization in India has developed with the GMB belt as its center. West Bengal and Bangladesh too are known as the land of rivers. In both these areas hundreds of rivers, flooded river basins, oxbow lakes, dug wells, and wetlands are available (Fig. 12). The amount of surface water available per head in West Bengal and Bangladesh is 7,000 and 11,000 m^3, respectively. The annual average rainfall is 1,800 mm. In spite of this, there is irresponsible use of groundwater for agriculture. Consequently, poisons like arsenic and fluoride have risen to the surface and they still do some times. If the villagers had been made aware before, and with villagers participation, a proper watershed management had been considered, they would have never faced this problem. Drawing water from safe tube wells is all right, but only after using all of the available surface sources. The arsenic-affected areas of West Bengal and Bangladesh have a popular saying: 'as cheap as water'. That saying has now turned into a joke. As the population increases, the need of water also increase; however, the available sources

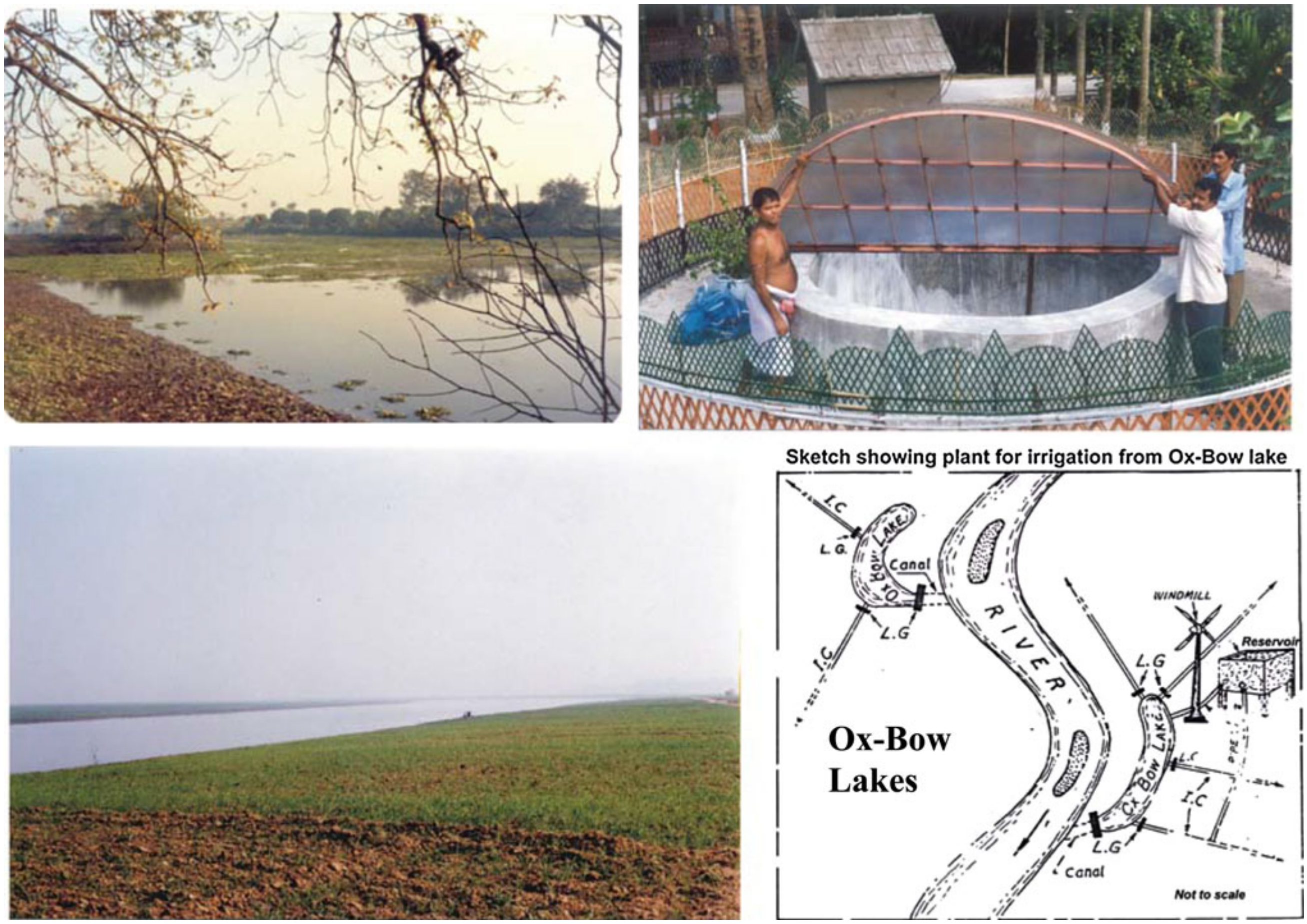

Fig. 12 Sources of surface water in West Bengal-India and Bangladesh

decreased and with time will decrease more. In arsenic-affected areas of West Bengal and Bangladesh, deep tube-well water is considered as a potential source of safe water and as a result of which both public and private sectors have already started using it. Should water from deep tube wells be used in an insensitive manner, there might be chances of arsenic from the shallow levels contaminating the deeper ones. In the current circumstances, drawing large amounts of water from deep tube wells might pose a danger in the future. Another word of caution: the deepest layers of water take thousands of years to form, but can dry up through a few years of insensitive use. As an example, drying of the deep water layer which took 10,000 years to form, in Rajasthan in India, in just 10 months due to callous and unscientific use for irrigation, is a case in point. Fluoride and arsenic in hand tube-well water have already been identified. If continued, there might be greater menaces awaiting in the future.

Conclusion

Although the first case of arsenicosis was revealed in West Bengal in the early 1980s, the widespread contamination was not recognized until 1995. A similar pattern followed in the late recognition of groundwater arsenic contamination of Bangladesh. In Bihar, to date there are 12 arsenic-contaminated districts by the side of river Ganga and in 6 districts subjects identified with arsenical skin lesions since the discovery of arsenic contamination back in 2002, and more are coming with the continuing surveys. It is predicted from this up-to-date preliminary survey from UP and Bihar that the districts lying in the area, where Ganga and other tributaries originating from the Himalaya shifted in course of time, would be arsenic contaminated. The areas of UP and Bihar, adjacent to arsenic-contaminated Terai region of Nepal, could also be affected. Groundwater arsenic contamination from Assam and Manipur hass already surfaced. There is a need to know the arsenic situation in the other five North-Hill states. In GMB-Plain alone at present more than 100 million people are at risk from groundwater arsenic contamination; at present only in India 62 million people are suffering from fluorosis, a crippling disease. The presence of uranium, boron, and manganese in groundwater of Bangladesh above WHO-prescribed limiting values has already been reported (DPHE 1999).

During the past 7–8 years field survey, it has been noticed that when a community, with the help of researchers, participated for arsenic safe water supply through treatment plants there was success. The authors believe that unless researchers, aid agencies, and government come forward to help community to spread the awareness among people about danger of arsenic toxicity, importance of analysis of arsenic in water, importance of arsenic safe water, and other social and socio-economic problem, they will not be able to combat the arsenic, fluoride, and similar contaminations.

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