

Extent and Severity of Groundwater Arsenic Contamination in Bangladesh

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Abstract: *In Bangladesh, the majority of the irrigation and drinking water is supplied from underground sources due to the limitation of surface water. In recent years, arsenic contamination has emerged as a fresh blow to the country. This paper gives an overview of the extent and severity of groundwater arsenic contamination in Bangladesh, as well as a review of the latest statistics and findings of numerous investigations about this issue. Recent reports of the British Geological Survey show that the groundwater in all 61 surveyed districts out of 64 is now contaminated with arsenic. On the other hand, a survey report of School of Environmental Studies, Jadavpur University, and Dhaka Community Hospital shows 47 districts are contaminated. The population exposed to the arsenic poisoning through drinking water is more than 25 million. In regard to arsenic pollution, Bangladesh is the most vulnerable country in the world. Unfortunately, until now, the cause of groundwater arsenic contamination has not been detected. Initially, several anthropogenic sources of arsenic were presented. Gradually, all were rejected based on the field observations. Finally, it was recognized that the source of arsenic is in the geological deposits. The two prevailing hypotheses, pyrite oxidation and oxy-hydroxide reduction, describe the cause of contamination. However, neither has been studied thoroughly with accurate field data. Therefore, the verdict is still out whether to support one hypothesis over the other. Thousands of people are suffering from arsenic diseases ranging from melanosis to skin cancer and gangrene, and many have even died. Unfortunately, there is no specific treatment for chronic arsenicosis, other than ceasing further intake of arsenic contaminated water. To overcome this predicament, awareness of the problem and the creation of watershed management are necessary.*

Keywords: Bangladesh, groundwater, arsenic contamination, causes, remedies.

Introduction

Bangladesh lies in the northeastern part of South Asia between 20°34' and 26°38' north latitude and 88°01' and 92°41' east longitude. She is bounded by India on the west, the north and the northeast, Myanmar on the southeast, and the Bay of Bangal on the south. The area of the country is 147,570 km² with an estimated population of 129.6 million for the year 2000 (BBS, 1998). The country is known as a land of natural calamities, where flood and drought are the normal phenomena. In recent years, arsenic poisoning has emerged as an additional burden to the country.

In Bangladesh, the Department of Public Health Engineering (DPHE) first detected arsenic in drinking water in 1993, and the issue came in lime light at the beginning of 1995. Recent findings of the British Geological Survey (BGS) show that groundwater of 61 surveyed districts, out of a total of 64, is contaminated with arsenic (BGS, 1999). However, survey results of the School of Environmental Studies (SOES) and Dhaka Community Hospital (DCH) show that 47 districts are contaminated (SOES-

DCH, 2000). The population exposed to the arsenic poisoning through drinking water is more than 25 million. Thousands of people are suffering from arsenic diseases ranging from melanosis to skin cancer and gangrene. In 241 villages where arsenic patients were suspected, thousands of arsenic patients and a total of 40 deaths due to arsenic-related diseases were identified by the SOES-DCH survey (SOES-DCH, 2000).

Presently, Bangladesh has about 1.8 million hand tubewells (HTWs) supplying drinking water from underground sources to more than 90 percent of 129.6 million people. She has also about 26,000 deep tubewells (DTWs), 630,000 shallow tubewells (STWs), and 140,000 manual suction lift wells (MSLWs) lifting groundwater for irrigation purpose (NMIDP, 1998). Using all these wells, water of more than 12,000 million m³ is pumped every year from the underground water sources. Over 90 percent of all groundwater abstraction is used for irrigation. Unfortunately, many of the tubewells are not supplying safe drinking water; rather, they pump the arsenic contaminated groundwater. Until now, only 50,000 out of the above

mentioned tubewells have been investigated by various government and non-government agencies. Although the government has a plan to survey at least all the tubewells supplying drinking water, it has not completed this task. Therefore, the actual picture of the severity of arsenic contamination is not yet revealed.

At present, arsenic has been taken into account as a dangerous environmental pollution and detected as a serious health risk in many countries of the world. Arsenic contamination has been reported from Argentina, Mexico, Chile, USA, Taiwan, Mongolia, Thailand, Philippines, China, Japan, India, as well as Bangladesh. But in terms of severity of the problem, Bangladesh tops the list. Some of the arsenic polluted countries of the world with the affected population are shown in Table 1.

The arsenic contamination is not only a health hazard for the people; it also affects the environment and creates social problems. Unfortunately, there is no treatment for arsenicosis, but people must stop drinking arsenic contaminated water, and government agencies should raise the awareness of the population about the problem.

So far, three main reports (BGS, 1999; SOES-DCH, 2000; DCH, 2000) and many papers and articles (Karim, 2000a; Karim, 2000b; Begum and Karim, 2000; Kamal and Karim, 2000; Karim et al., 1997; Nickson et al., 1998; Nickson et al., 1999; Adel, 2000; Husain, 2000; Bridge and Husain, 1999a; Bridge and Husain, 1999b; Bridge and Husain, 2000a; Bridge and Husain, 2000b; Khalequzzaman, 1999; Hossain et al. 2000; Anwarul Islam et al., 1998, etc.) related to Bangladesh groundwater arsenic contamination have been published in different local and international journals, daily newspapers, Internet, etc. However, none has complete updated information about the extent and severity of the problem, population exposed to contamination, cause of contamination and its remedy, and

number of people suffering from arsenosis. Moreover, there are some reports that contradict each other. This paper describes the latest statistics of groundwater arsenic contamination in Bangladesh, its eventual causes and remedies.

Nature of Arsenic and its Occurrence

Arsenic is a metalloid element, which is brittle in nature and gray or tin white in color. Arsenic cannot be found in nature as a free element. It can be found as a compound of oxygen, chloride, sulfur, carbon, hydrogen, lead, mercury, gold, and iron. There are as many as 150 species of arsenic bearing minerals that exist in the nature. However, only three of them are considered as arsenic ore because the amount of arsenic is higher in these three compounds. Moreover, they are more available than other arsenic compounds. These three compounds are: Realgar or arsenic disulfide (As_2S_2); Orpiment or arsenic trisulfide (As_2S_3); and Arsenopyrite or ferrous arsenic sulfide ($FeAsS$). Arsenopyrite has been primarily identified as the main source of arsenic pollution in Bangladesh. Chemically, arsenic compounds are two types: inorganic and organic. Inorganic arsenic is again divided into two types: trivalent and pentavalent. Inorganic arsenic is more toxic than the organic ones. The trivalent arsenic (arsenite, $As(III)$) is 60 times more toxic than the pentavalent arsenic (arsenate, $As(V)$). Usually, there are four types of arsenic compounds that exist in water, in inorganic form: arsenite ($H_2AsO_3^-$) and arsenate ($H_2AsO_4^-$), which are commonly found in the groundwater of Bangladesh, and in organic form: methyl arsenic acid ($CH_3AsO(OH)_2$) and dimethyl arsenic acid ($(CH_3)_2As(OH)$).

Arsenic is found in low concentrations in naturally occurring materials comprising less than one percent of

Table 1. Arsenic Polluted Countries of the World With Affected Population and Their Reason

Name of the Country	Year of Pollution	Population Affected by Arsenic	Maximum Range of Pollution (mg/l)	Main Reason of Pollution
Argentina	1938–1981	20,000	0.1–2.0	Natural soil pollution
Mexico	1963–1983	200,000	0.1–0.5	Oxidation of arsenic bearing minerals
Chile	1957–1969	130,000*	0.8–1.3	River cutting through arsenic bearing formation
USA	1972–1982	3,000,000*	0.045–0.092	Oxidation of pyrite, reduction of ferric oxide, etc.
Taiwan	1961–1985	100,000	>0.05	Oxidation of pyrite
Mongolia	1962–1989	1,774	>0.05	Over-irrigation
Thailand	1987–1998	18,000*	0.05–5.0	A tin mine
Philippines	1992–1995	39	-	Geothermal power plant
China	1953–1993	1,546	-	Use of coal as fuel
Japan	1945–1995	217	-	Metal and coal mine
India	1978–1998	200,000	0.05–3.7	Over-exploitation of groundwater (pyrite oxidation)
Bangladesh	1993–2000	21,000,000 (at least)	0.052–4.727	Over-exploitation of groundwater (pyrite oxidation) or arsenic released under reducing condition

* = Population at risk, actual affected is unknown and - = data not available.

Source: Akram (1997), BGS (1999), and SOES-DCH (2000).

rocks, coals, and soils. It is widely distributed in the soil profile as compound of different minerals and found in nominal amounts in all organisms. Most of Bangladesh and the arsenic-affected areas of West Bengal, India, lie on the Quaternary alluvial plains of the Bengal Basin. The Garo-Rajmahal Gap broad alluvial plains of the Ganges and the Brahmaputra, so-called Himalayan Foredeep, extend to the northwest and northeast, respectively. To the north of this line, lie the crystalline rocks and meta-sediments of the great Himalayan thrust blocks. West Bengal (Purulia District), Bihar, and the Shillong Plateau (north of Sylhet and Mymensingh districts of Bangladesh) are extensive areas of Precambrian high metamorphic rocks and granites with widespread sulphide mineralisation. The eastern portion of the Indian Platform also includes important Rajmahal coalfield. Because of their position close to where the Ganges enters Bangladesh, some authors have suggested that they may be the primary source of arsenic in the Bengal alluvium (BGS, 1999).

Arsenic Contamination Scenario in Groundwater Environment of Bangladesh

Spatial Extent of Arsenic Contamination

After DPHE addressed the groundwater arsenic contamination problem in Bangladesh in 1993, DPHE itself and many other government and non-government organizations, such as Grameen Bank (GB), Non-Government Organization (NGO) Forum, Dhaka Community Hospital (DCH), School of Environmental Studies (SOES) of Jadavpur University, Bangladesh University of Engineering and Technology (BUET), Bangladesh Council for Scientific and Industrial Research (BCSIR), NRECA (a US consulting firm working for Rural Electrification Board of Bangladesh), DANIDA (Official Danish Aid Agency), Bangladesh Rural Advance Committee (BRAC), and British Geological Survey (BGS), started working on the groundwater arsenic contamination issue. For every organization the first job was to identify the arsenic contaminated wells. According to the World Health Organization (WHO), the safe limit of arsenic in drinking water is 0.01 mg/L. However, WHO set the maximum permissible limit of arsenic in drinking water for Bangladesh and India as 0.05 mg/L. Sophisticated laboratory facilities are required to accurately detect arsenic in groundwater. Unfortunately, very limited number of these facilities are available in Bangladesh. Moreover, laboratory method of arsenic detection is expensive and time consuming. Therefore, many organizations started groundwater arsenic detection by the field-kit method. 'Field-kit' is an instrument, which is designed to identify the presence of arsenic with Bangladesh standard in drinking water. It is a yes-no instrument that cannot detect absolute concentration of groundwater arsenic. This method is very simple, but the difficulty is that it cannot detect arsenic with reliability if the concentration is less than 0.2 mg/L. A total of 22,777 water samples

were collected and tested by field-kits by the DPHE, GB, and NGO Forum to identify arsenic contaminated water wells. On the other hand, a total of 9,037 water samples were collected and tested in the laboratory by the DCH/SOES, DPHE, BUET, BCSIR, NRECA, DANIA, 18DTP (Eighteen District Towns Water Supply Project), Safiuallah, Nickson, BRAC, and BGS. In its recent reports, the BGS has presented two separate figures: one based on field tests and another based on laboratory tests to describe the extent of groundwater arsenic contamination in Bangladesh (BGS, 1999). Though in both figures the index of arsenic contamination is expressed as a percentage of wells contaminated, these two figures are different. The reason is that field-kits results are not 100 percent accurate and for many locations samples collected for laboratory test are not adequate. Moreover, none of the above methods covered all the districts. Therefore, a combination of field and laboratory test results would give better picture of the extent of groundwater arsenic contamination in Bangladesh. Until 1998, a total of 31,651 water samples were tested by field and laboratory tests by different organizations. Out of these, 30,742 were collected from shallow wells (<200 m) and 909 from deep wells (>200 m). It has been found that 7,942 samples out of the 30,742 from shallow wells and 34 samples out of the 909 from deep wells are contaminated with the percentages 25.8 and 4, respectively. The arsenic contaminated districts of Bangladesh are shown in Figure 1. Figure 2 shows the total number of tests performed in each district. Figure 2 will help to assess the representative of the data presented in Figure 1. From Figure 1, it is apparent that all the surveyed districts (61 out of 64) show the presence of arsenic contamination. However, nine contaminated districts out of 61 show that a very limited percentage (<1%) of wells are contaminated. Three districts (i.e., Rangamati, Khagrachhari, and Bandarban) were not surveyed by any organization. One reason may be that these three districts are mainly hilly areas, with 8.73 percent of the total area of Bangladesh and only 0.92 percent of the total population. Another reason may be that no primary symptoms of arsenic patient were found there. Similarly, out of 465 thanas of the surveyed 61 districts, 54 were not surveyed at all by any organization. Thanas is a small administrative unit of Bangladesh, which is a sub-division of a district. In each thana there is a police station. That is why sometimes it is called a "Police Station." In Bangladesh, there are 64 districts and 490 thanas. Moreover, the number of samples taken from each district is not uniform (Figure 2), which suggests that there is a sampling bias of arsenic detection in the country. Out of the 411 surveyed thanas, 270 were found contaminated having arsenic above Bangladesh standard (0.05 mg/L). Neglecting all the difficulties, we can use Figure 1 to see the extent of groundwater arsenic contamination in Bangladesh. Figure 1 shows that almost the whole of the country is contaminated with arsenic. The severe problem is in the southern (coastal area) and

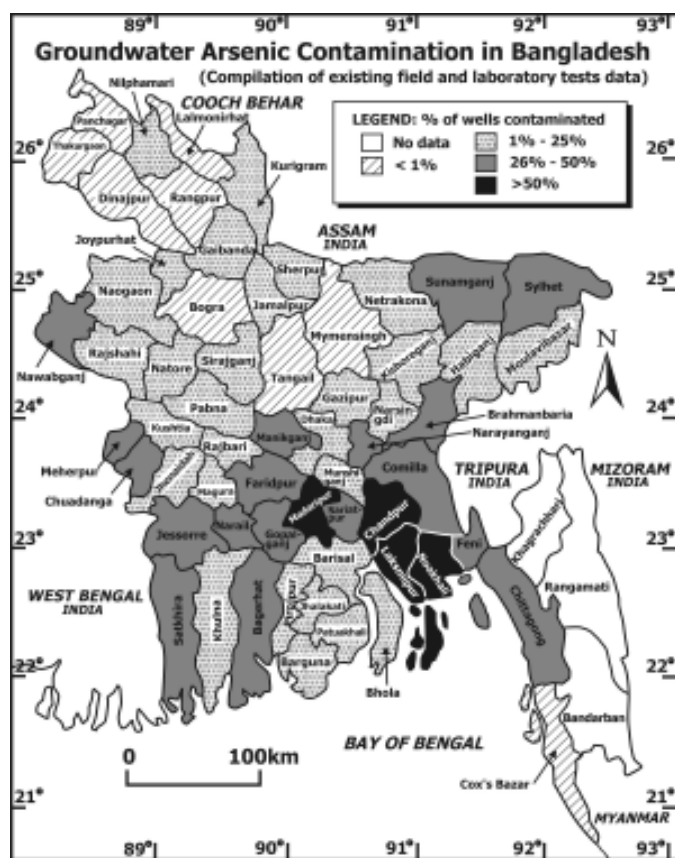


Figure 1. Groundwater arsenic contamination in different districts of Bangladesh based on compilation of field and laboratory test data (Source: BGS, 1999).

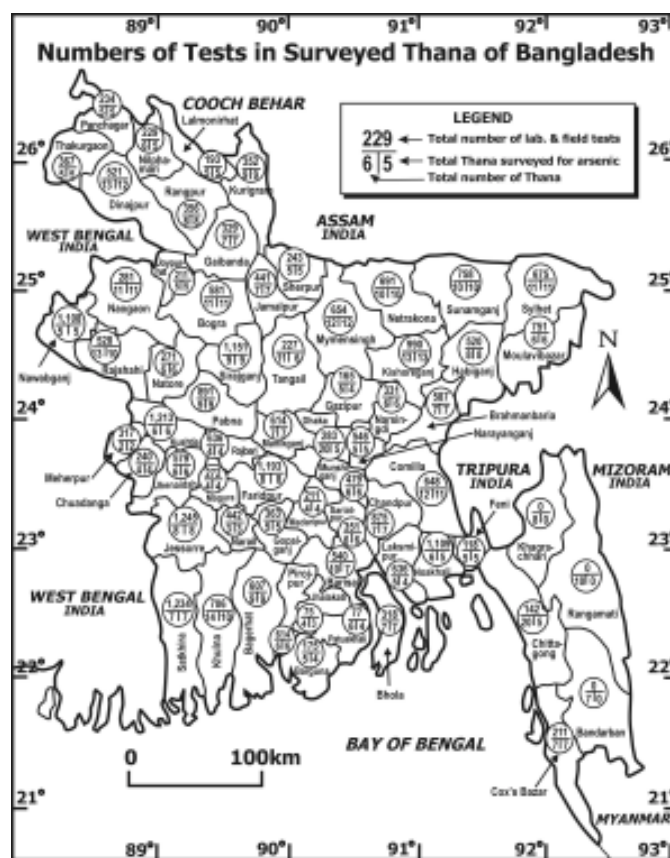


Figure 2. Districts of Bangladesh showing surveyed and total number of thanas and total numbers of tests performed for groundwater arsenic investigation (Source: BGS, 1999).

northeast parts of the country. Table 2 shows ranges of contamination and their respective percentages of area and population under contamination.

The badly affected districts are Brahmanbaria, Comilla, Feni, Narayanganj, Sariatpur, Narail, Satkhira, and Nawabganj. The disastrous situation is in the districts of Laksmipur, Noakhali, Madaripur and Chandpur (Figure 1). The Ganges, Megna, and Atri Floodplains, the tidal regions and the coastal plains are the major physiographic regions vulnerable to arsenic contamination (Figure 3).

In April 2000, SOES and DCH jointly published a report on Bangladesh groundwater arsenic contamination (SOES-DCH, 2000), which shows figures different from those in the BGS report. According to SOES-DCH (2000), up to February 2000, 22,003 tubewell water samples were analyzed in the laboratory and it was found that in 73.34 percent and 53.47 percent samples the arsenic concentrations were above the WHO and Bangladesh standards, respectively. SOES-DCH (2000) also found that out of the 64 surveyed districts, in 54 districts arsenic in groundwater was above 0.01 mg/L and in 47 districts above 0.05 mg/L. Figure 4 shows arsenic contaminated districts according to the SOES-DCH survey. The main difference between the combined analysis (Figure 1) and the SOES-DCH survey (Figure 4) is that Figure 1 shows all 61 sur-

veyed districts were contaminated with concentration of > 0.05 mg/L, whereas Figure 4 shows seven completely safe districts (i.e., Panchagarh, Thakurgaon, Dinajpur, Naogaon, Moulabibazar, Patuakhali, and Cox's Bazar), and seven districts (i.e., Nilphamari, Lalmonirhat, Gaibanda, Joypurhat, Dhaka, Barguna, and Bhola) were over the WHO safety limit but under the maximum permissible limit. Three no-surveyed districts of combined analysis (Khagrachhari, Rangamati, and Bandarban) were found contamination free by the SOES-DCH survey. Undoubtedly, the SOES-DCH survey gives more accurate results

Table 2. Percentage of Arsenic Contamination and Their Respective Percentage of Area and Population Under Contamination

Percentage of Wells Contaminated	Number of Districts	Percentage of Area	Percentage of Population
<1	9	15.85	17.00
1 ~ 25	30	42.81	46.39
26 ~ 50	18	27.25	29.42
>50	4	5.36	6.27
Unknown (not surveyed)	3	8.73	0.92
Total	64	100.00	100.00

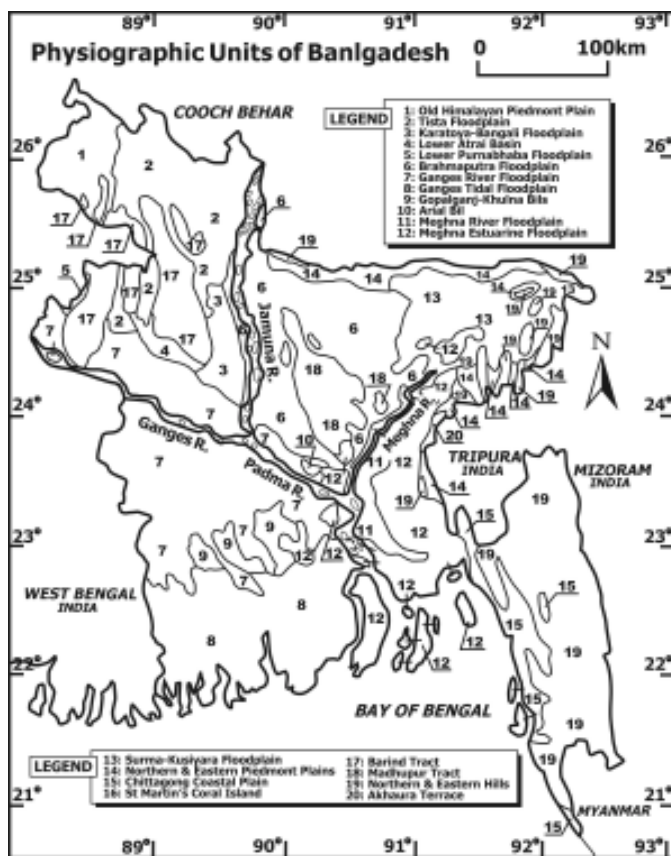


Figure 3. Different physiographic units of Bangladesh (after FAO, 1988).

than field-tests, but has a shortcoming: the samples analyzed are still insufficient in number. Another important matter is that though SOES-DCH surveyed all 64 districts out of the total 490 thanas, they covered only 222 thanas. Therefore, if they would cover all the thanas, there is a possibility of increasing number of districts contaminated by arsenic. Another limitation of SOES-DCH survey is that their samples are biased as they first identified arsenic patients and then analyzed tubewells water used by those arsenic patients. However, there may be a doubt whether 61 or 47 districts out of 64 are contaminated, while there is no doubt that the country is facing with severe groundwater arsenic problem. To get a clear and accurate picture of groundwater arsenic contamination, a coordinated survey of all drinking water wells and some sampled irrigation wells throughout the country is necessary. Adequate numbers of samples should be collected without any bias and they should be analyzed accurately in the laboratory. Mitigation of arsenic contamination depends on accurate identification of the contaminated wells, but most of the organizations are not strictly following the appropriate identification procedure.

Depth-dependent Distribution of Arsenic Contamination

The BGS tested 2,022 tubewells water samples from

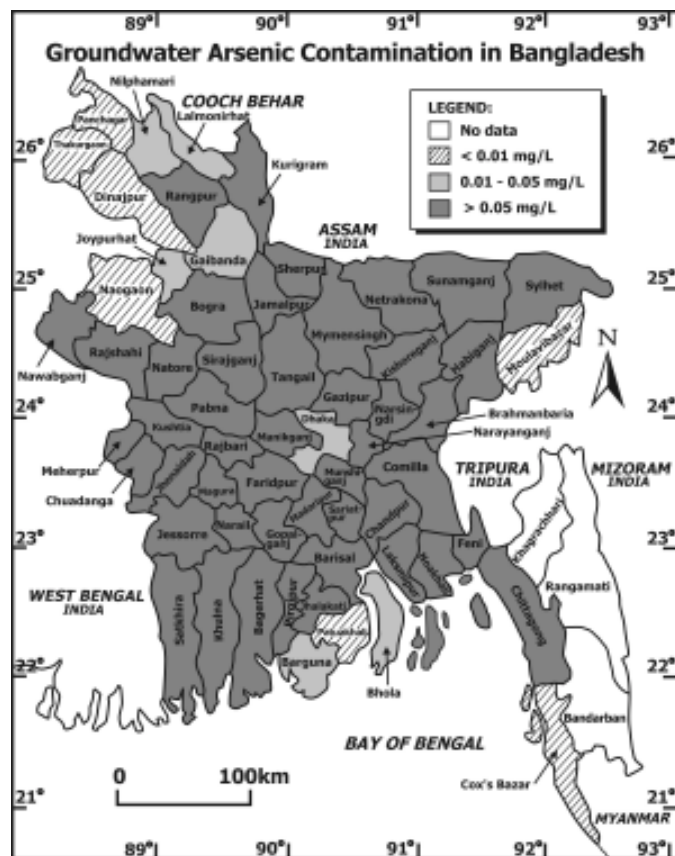


Figure 4. Groundwater arsenic contamination in different districts of Bangladesh (after SOES-DCH, 2000).

41 districts of Bangladesh. Some 14 percent of those were taken from wells deeper than 200 meters. They found that only about 1 percent of the deep well samples was contaminated above the Bangladesh standard. This is contrasted with 41 percent contaminated wells in the shallower aquifers. Most of the shallow wells are between 10 m and 70 m deep (BGS, 1999).

The SOES-DCH found similar results. They analyzed arsenic from 15,969 tubewells of 6.4 m to 400 m deep over 47 arsenic affected districts. Their results show that around the depth of 15-20 m there is an increase of arsenic concentration and then with increasing depth the arsenic concentration decreases (SOES-DCH, 2000).

Population Exposed to Arsenic Contamination

The BGS report states that the probable number of people exposed to arsenic concentrations above the Bangladesh standard (0.05 mg/l) is about 21 million. This number would be roughly doubled if the WHO guideline value of 0.01 mg/l were adopted as a standard (BGS, 1999). On the other hand, the SOES-DCH (2000) report shows that these numbers are 25 million and 52 million out of 85 million people in 43 districts, respectively. Therefore, if we consider all 64 districts of the country, the population exposed to arsenic concentrations above the Bangladesh standard may be as much as around 40 million. However,

to get a more accurate figure, it is first necessary to identify the accurate number of drinking tubewells along with the degree of contamination. For example, SOES-DCH on the basis of their random survey results estimated that 3.5 million drinking tubewells were prevailing in the country (SOES-DCH, 2000). But just after a few months, DCH deduced from the survey results for 500 villages that there was a possibility of having 11 million drinking tubewells in the country (DCH, 2000).

Arsenic-related Health Hazards

Skin diseases are the common effects of arsenic poisoning. The toxic effect of arsenic species depends mainly on their chemical form, route of entry, age, sex, doses, and duration of exposure. A number of skin lesions have been attributed to chronic exposure to arsenic compounds. Symmetric hyperkeratosis of the palms and soles is a characteristic finding after long-term ingestion of inorganic arsenic in drinking water. Hyper pigmentation (melanosis) of the skin is commonly encountered and occurs throughout the body. Melanosis is not always associated with keratosis, but keratosis is always associated with melanosis. Melanosis is also observed in tongue and buccal mucus membrane (DCH, 1998). Other effects of arsenic are: 1) liver enlargement and cirrhosis of the liver; 2) myocardial degeneration and cardiac failure; 3) peripheral neuropathy affecting primary sensory function; 4) diabetics mellitus and goiter; and 5) skin cancers. Three types of skin cancers are observed: Bowen's disease, Basal cell carcinoma, and Squamous cell carcinoma. These cancers are frequently multiple in origins and develop primarily from arsenical keratosis (DCH, 1998). In Bangladesh, the majority of the patients are in the initial and middle stages.

By February 2000, the water samples from 22,003 hand tubewells, around 11,000 randomly selected hairs, nail, urine, and skin-scale samples from 1,063 affected villages were analyzed in laboratory under the SOES-DCH

survey. The presence of high-level arsenic was detected in 53.47 percent of the water samples, 83.15 percent of the hair samples, 93.77 percent of the nail samples, and 95.11 percent of the urine samples. Of the total, 20.6 percent had identified skin lesions (SOES-DCH, 2000). Altogether, some thousands of arsenic patients and 40 deaths due to arsenic-related diseases were identified by the SOES-DCH survey only for 241 affected villages. There are 86,000 villages in the country out of which at least 25,000 may be arsenic affected. In the past it was assumed that the symptoms of arsenic toxicity may take eight to 14 years to be manifested in human body after the patient starts drinking arsenic contaminated water (DCH, 1998), but the SOES-DCH survey revealed arsenic symptoms in the body of children ranging from four to seven years old also. The percentage of identified arsenic patients seems to be higher than the national average, since the selected villages were biased towards more affected areas. But the true situation may be different; as only a small percentage of the true patients in the affected areas were identified due to many social constraints. Another detailed survey of DCH which covered 500 arsenic affected villages shows that 52.17 percent tubewells are contaminated, 56.15 percent of the total population (of affected 500 villages) is at risk, and only 0.28 percent of the total population is identified as arsenic patients (DCH, 2000). The above findings reveal a disastrous situation regarding arsenic pollution in Bangladesh. Table 3 shows the latest statistics regarding groundwater arsenic contamination in Bangladesh.

Sources and Causes of Arsenic Contamination

Sources of Arsenic Contamination in Bangladesh

In different countries the potential source of arsenic contamination is different. For arsenic contamination in Bangladesh, initially, several anthropogenic sources were

Table 3. Latest Statistics of Arsenic Contamination with Affected Areas and Population in Bangladesh

<i>Parameter</i>	<i>BGS (1999)</i>	<i>SOES-DCH (2000)</i>
Total area of Bangladesh	147,570 km ² *	147,570 km ² *
Total population of Bangladesh	129.6 million*	129.6 million*
Total number of districts of Bangladesh	64*	64*
Number of districts surveyed for investigation of arsenic contamination	61	64
Number of districts having arsenic above maximum permissible limit	61	47
Area of affected districts	134,275 km ²	112,407 km ²
Population of affected districts	128.4 million	93.5 million
Total number of thanas of affected districts	465	357
Number of thanas of affected districts surveyed	411	222
Number of thanas having arsenic >0.05 mg/L	270	147
Area of these thanas having arsenic >0.05 mg/L	80.1 million	46.2 million
Population of exposed to arsenic contamination (Population who drink water with arsenic >0.05 mg/L)	21 million	25 million**

* = BBS (1998) and ** = estimated for 43 districts of Bangladesh.

considered, such as: 1) use of fertilizers, pesticides, insecticides, and herbicides containing arsenic; 2) use of arsenic compounds as preservatives in wooden electric poles of Rural Electrification Board; 3) tubewell filters coated with arsenic compound; 4) industrial waste disposal; and 5) enhanced leaching beneath irrigated lands (BGS, 1999). Gradually, all these anthropogenic sources were rejected based on the field observations. Finally, it was recognized that the source of arsenic is in the geological deposits.

Causes of Arsenic Contamination in Bangladesh

Two hypotheses are prevailing to describe the cause (mobilization) of arsenic into groundwater of Bangladesh. These are: a) Pyrite Oxidation and b) Oxy-hydroxide Reduction.

Pyrite Oxidation Hypothesis

Arsenic is assumed to be present in certain sulphide minerals (pyrites) that are deposited within the aquifer sediments. Due to the lowering of water table below deposits, arsenopyrite oxidized in the vadose zone releases arsenic as arsenic adsorbed on iron hydroxide. During the subsequent recharge period, iron hydroxide releases arsenic into groundwater. According to this hypothesis, the origin of arsenic rich groundwater is man-made, which is a recent phenomenon. The mechanism is illustrated in Figure 5.

The intensive irrigation development in the country supports the above hypothesis. Irrigation development in Bangladesh using DTWs and STWs started in the early

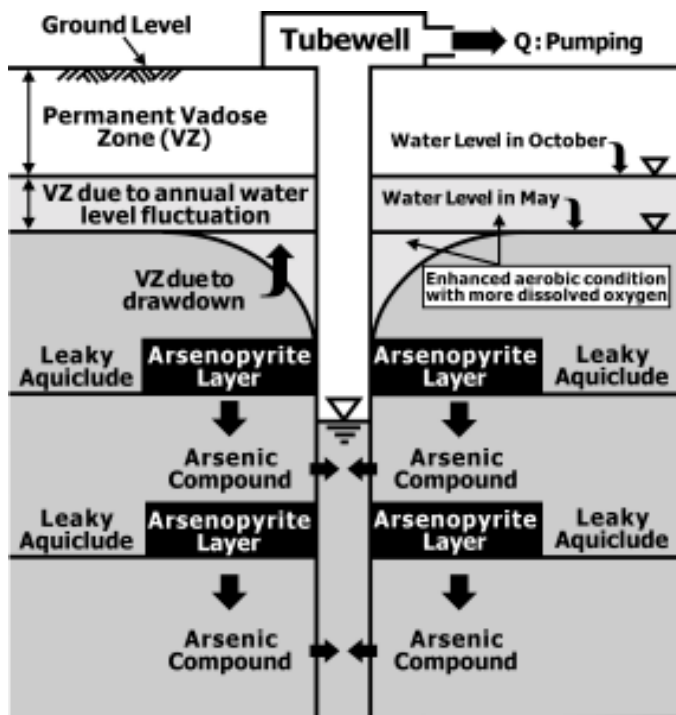


Figure 5. Aerobic condition in groundwater around a tubewell (after Karim et al., 1997).

1960s and rapidly expanded in the early 1980s. At first DTW irrigation became popular in the country because the government of Bangladesh (GOB) subsidized farmers to purchase DTWs, but under the privatization policy of the government and according to the suggestion of the World Bank since 1991, the GOB stopped giving loans to the farmers. As a result, DTW irrigation development became stagnant. Since then, STWs have become popular, mainly due to their low cost and due to the withdrawal of rules and regulations of tubewell installation by the GOB under the new privatization policy. Only during the irrigation season between 1995/1996 season and the 1996/1997 season, the area under STWs increased by 7.7 percent. The irrigated areas under DTWs, LLPs (low lift pumps), and the traditional system decreased by 11.7, 1.2, and 20 percent, respectively. As a result, the overall area under the minor irrigation increased by 1 percent. During this period, the area under groundwater irrigation increased by 3.1 percent, while the area under surface water irrigation decreased by 3.8 percent. The contribution of groundwater to total irrigated area increased from 41 percent in 1982/1983 to 71 percent in 1996/1997 with an increasing tendency in each year, while the contribution of surface water steadily declined from 59 to 29 percent over the same period (NMIDP, 1998). The growth of irrigation area since 1983 in terms of irrigation technologies is shown in Figure 6.

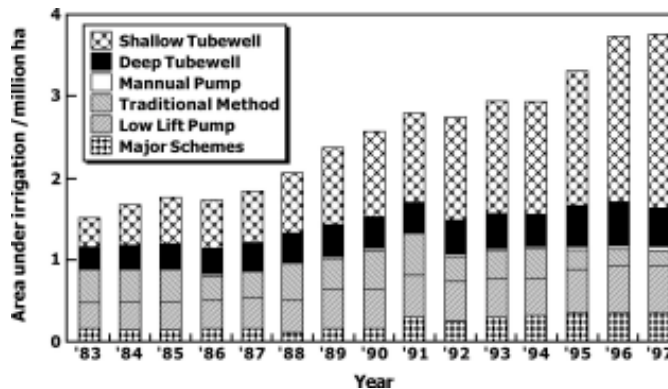


Figure 6. Growth in irrigated areas of Bangladesh since 1983 (after NMIDP, 1998).

The lack of prior reported arsenic patients before irrigation development based on groundwater extraction in the country also supports the pyrite oxidation hypothesis, although a significant number of people were using groundwater through tubewells or dug wells as a drinking water source at that time. Until only two years ago, groundwaters in Rangpur, Jamalpur, and Bogra districts had been considered as safe, but now they are not only contaminated, but also these areas contain many identified arsenic patients (SOES-DCH, 2000).

Oxy-hydroxide Reduction Hypothesis

Arsenic is assumed to be present in alluvial sediments

with high concentrations in sand grains as a coating of iron hydroxide. The sediments were deposited in valleys eroded in the delta when the stream base level was lowered due to the drop in sea level during the last glacial advance. The organic matter deposited with the sediments reduces the arsenic bearing iron hydroxide and releases arsenic into groundwater. According to this hypothesis, the origin of arsenic rich groundwater is due to a natural process, and it seems that the arsenic in groundwater has been present for thousands of years without being flushed from the delta.

The Oxy-hydroxide Reduction hypothesis to describe the mobilization of arsenic from the source to the groundwater for Bangladesh basin was first proposed by Nickson et al. (1998).

Investigations of Arsenic Mobilization Hypotheses

Although primary investigations regarding rapid irrigation development and rate of water abstraction support the pyrite oxidation hypothesis, BGS rejected it based on some space-dependent correlations. The BGS investigated five correlations: 1) the correlation between gross water abstraction and percent of wells contaminated; 2) the correlation between maximum water level below ground surface and percent of wells contaminated; 3) the correlation between aquifer transmissivity and percent of wells contaminated; 4) the correlation between sulphate concentration and arsenic concentration; and 5) the correlation between potential recharge and percent of wells contaminated, to see the validity of the pyrite oxidation hypothesis. They found no significant but negative trends of relationships for correlations 1 to 4 (above) and no significant but positive trend of relationship for Correlation 5 (BGS, 1999). Therefore, they rejected pyrite oxidation hypothesis. However, a recent investigation by Fazal et al., (in press) points out that due to the errors in the key parameter employed BGS results of percentage of wells contaminated, are not reliable to make any conclusion about pyrite oxidation. Moreover, the space-dependent relationships among different hydrogeological parameters for the heterogeneous aquifer system are not valid to represent time-dependent phenomenon. Therefore, conclusions made by the BGS about this issue are not valid.

In order to support oxy-hydroxide reduction hypothesis, the BGS investigated three correlations: 1) the correlation between extractable iron concentration and arsenic concentration; 2) the correlation between arsenic concentration and the reducing conditions (pH-Eh); and 3) the correlation between arsenic concentration and depth of contamination. For the first and second correlations, they found significant positive relationships, and therefore they accepted oxy-hydroxide reduction hypothesis (BGS, 1999). However, regarding the appropriateness of considering extractable iron concentration, Bridge and Husain (2000a;

2000b) noted that the correlation between extractable iron and arsenic does not necessarily imply the adsorption (oxy-hydroxide reduction) hypothesis, and questions were put forward by Adel (2000) for the availability of pH, Eh data. Thus, the above two relationships became confusing. On the other hand, for the third correlation BGS found a significant negative relationship, which contradicts acceptance of oxy-hydroxide reduction hypothesis. A detail analysis of the courses of groundwater contamination with arsenic can be found in another paper by the authors in this issue of *Water International*.

Remedies of Arsenic Problem

Treatment for Arsenicosis

Unfortunately there is no specific treatment for chronic arsenicosis. Stopping further intake of arsenic contaminated water and drinking arsenic-free water improves the cases. A recent report of DCH (2000) states that chronic arsenicosis cannot be cured, but the symptoms are reversible up to certain point if a patient discontinues ingesting contaminated water. If a patient crosses this threshold, he/she still needs medical assistance to save his/her life. For instance, amputation may save the life of a patient suffering from gangrene. Palliative drugs may also be administered along with micronutrient supplement (DCH, 2000).

Watershed Management

For a proper remedy of the problem, at first all of the contaminated tubewells should be identified accurately, and then the proper cause(s) of the contamination should be investigated. The over-abstraction of groundwater should be regulated. In highly affected areas where most tubewells are found contaminated, the immediate solution may be to share safe tubewells. If that is not possible, water from contaminated tubewells should be used after filtering to reduce concentration of arsenic. In the contaminated area, immediate installation of deep tubewell may be an alternative, as most of the deep aquifers are arsenic free. It is better to use alternative source of water, such as pond water with slow sand filtration and harvested rainwater, if possible. If no other options exist, it is urgent to shift to surface water use or construct arsenic treatment plants.

Conclusions

An investigation was undertaken to analyze the latest statistics regarding arsenic contamination of groundwater in Bangladesh. Attempt was made to provide an overview of the extent and severity of the problem, its probable causes, effects and remedies. The facts and urgent needs to be emphasized could be summarized as follows:

- Regarding arsenic pollution, Bangladesh, with 25 to 40 million people exposed to poisoning, is the most vulner-

able country in the world. Out of 64 districts of the country, 47 to 61 districts have arsenic content above the WHO recommended maximum permissible limit of 0.05 mg/L.

- Thousands of people are suffering from arsenic-related diseases ranging from melanosis to skin cancers and gangrene, and many even died. Unfortunately, there is no specific treatment for arsenicosis.
- Two hypotheses, pyrite oxidation and oxy-hydroxide reduction, are prevailing in Bangladesh to describe the cause of arsenic contamination. However, until now none of them has been studied thoroughly with accurate field data. The verdict is still out rather to support one hypothesis over the other.
- Arsenic contamination in Bangladesh is a serious national problem. To control and eradicate the ravages of the contamination, the exact cause(s) of contamination and its mobilization mechanism should be identified. Then a remedial action plan should be made with participation of experts in relevant fields and community representatives.

Acknowledgement

The authors would like to thank the Japan Society for the Promotion of Science (JSPS) for supporting this research from the post-doctoral research fund.

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Discussions open until March 1, 2002.

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