Groundwater Arsenic Contamination: Food Safety and Human Health Hazards in Bangladesh

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ABSTRACT

Groundwater is a remarkable source for supplying drinking water (more than 95% of total population) as well as in sustainable irrigated (70-80% of total irrigation) crop production in Bangladesh. Extent and severity of arsenic contamination of groundwater is a crucial issue and a threat to human health and food safety in Bangladesh. Out of 64 districts, water in 61 districts has arsenic concentration above safe limit. About 30 million people are directly at arsenic contamination risk. About 38,000 cases of arsenicosis patients are identified and it is suspected that over 0.2 million people have been suffering from arsenic-related diseases. Regarding arsenic pollution, probably, Bangladesh is the most vulnerable country in the world. Still now, the cause of groundwater arsenic contamination is unknown, although initially several anthropogenic sources were put forward. Gradually, all were rejected based on the field observations. Finally, it was recognized that the source of arsenic was naturally-occurring geological deposits. Two main hypotheses, "pyrite oxidation" and "oxy-hydroxide reduction" are put forward to clarity the source, cause, formation, mobilization and distribution of arsenic contamination. First hypothesis, contamination is human-made, which has a relationship with excessive groundwater withdrawal and second one, the contamination is natural. However, none of them have been studied thoroughly with accurate field data and evidence. Arsenic moves to human body mainly through drinking water and food. Rice having higher concentration of inorganic arsenic covers a large share of Bangladesh diet. Vegetables, having >80% water content, when irrigated with arsenic-contaminated water is likely to get contaminated by arsenic. High concentration of arsenic in soils accumulated through irrigation water might have serious negative impacts on agricultural environment, soil-crop quality and production, livestock and fishery production and its carry-over effect on food chain, thus, may jeopardize the country's food safely campaign.

Key words: Groundwater, Arsenic contamination, Food chain, Food safely, Soil-crop quality, Rehabilitation and sustainability, Bangladesh

INTRODUCTION

Water quality will become the principal limiting factor for sustainable development in many countries early in this century (Ongley, 1999). *"Everything living is created from water"* is an ancient quotation, which closely describes the importance of water (Anon., 1977). Alarming information has emerged in recent decades about the widespread presence of arsenic (As) in groundwater used to supply drinking water in many countries on all continents. Hundreds of millions of people, mostly in developing countries, daily use drinking water with arsenic concentrations several times higher than the World Health Organization (WHO) recommendation of 0.01mg/L of water. As contamination of groundwater in Bangladesh is now a well-known fact. In terms of extent and severity of the problem, Bangladesh is probably the most vulnerable country in the world. Out of 64 districts, 61 have arsenic concentration above the maximum permissible limit of 0.05 mg/L (Iqbal, 2004). Source of As in groundwater is naturally-occurring geological deposits at shallower depths (usually 12–46 m or 40-150 ft). The Department of Public Health Engineering (DPHE) of Bangladesh first detected arsenic in groundwater in 1993, and the issue came to limelight at the beginning of 1995. Population exposed to As poisoning through drinking water is about 36 million. It is suspected that over 0.2 million people are suffering from arsenic-related diseases, ranging from melanosis to skin cancer and gangrene. So far, about 38,000 As-patients are clearly identified and it is predicted that 0.20–0.27 million people will die of cancer from drinking As-contaminated water and foods in Bangladesh alone (Meharg and Rahman, 2003). This paper gives an overview of the extent and the severity of arsenic contamination of groundwater and its threat to human health and food safety in Bangladesh.

Historically, surface (river or pond) and dugwell water has been used as drinking water in Bangladesh. Due to gastrointestinal diseases, resulting from bacterial contamination of stagnant water, caused severe infant and child mortality. To overcome this problem through drinking safe water, UNICEF had started installing hand tubewells (HTW) across the country since 1970s and 1980s. Presently, Bangladesh has about 8.6 million hand tubewells (HTW), supplying drinking water from groundwater sources to >95% of 140 million people. The supply of pure drinking water has been one of the few success stories in the public health care. This helped reduce the water-borne diseases, while in mid 1990s, detection of arsenic in groundwater became a new issue to the nation. In 2006, UNICEF reported that 4.7 million (55%) of the 8.6 million wells in Bangladesh had been tested for arsenic of which 1.4 million (30% of those tested) had been showing them to be unsafe for drinking water: defined in this case as >0.05 mg/L. Although many people have switched to using arsenic free water where arsenic had been identified (51%), while no action had yet been taken by 34% of the peoples in contaminated areas in Bangladesh (UNICEF 2006). In 2000, a WHO report (Smith et al., 2000) described the situation in Bangladesh as: *"the largest mass poisoning of a population in history … beyond the accidents at Bhopal, India, in 1984, and Chernobyl, Ukraine, in 1986."*

Bangladesh is a small South Asian country (area 147,570 km^2) with a very high population (140 million) located between 20o34' and 26o38' North latitude and 88o01' and 92o41' East longitude. To feed huge population from limited cultivable land (8.3 million hectares), it has to adopt intensive irrigated agricultural products. Therefore, it has about 1,129,000 shallow tubewells (STW) and 27,000 deep tubewells (DTW), lifting groundwater for irrigation purpose (Rashid and Islam, 2006). Using all these pumps, about 13,000 million cubic meter (MCM) of water is pumped every year from the underground water sources. Over 90% of all groundwater extraction is used in irrigation purpose (Rashid, 1997; BBS, 2000).

The impact of As-contaminated irrigation water on agriculture and its carry-over effect on food chain is still a matter of conjecture. Sporadic researches provide disparate informations on adverse effect of arsenic on agriculture, and they are by no means conclusive. The matter is of crucial importance as groundwater is the major source (over 75%) of irrigation water in Bangladesh. Research to assess the risk of arsenic poisoning to human/animals through food chain and the impact of arsenic on crop production and agricultural environment is of paramount importance.

Arsenic contamination has been reported from many parts of the world but in terms of severity of the problem, Bangladesh tops the list, followed by India and China (Nordstrom, 2002). Arsenic is considered to be a dangerous environmental pollution and a serious health hazard. Some of the arsenic-polluted countries with affected population and the cause of the pollution are shown in Table 1.

However, three main reports (BGS, 1999; SES-DCH, 2000; DCH, 2000) and many papers/articles related to arsenic contamination of groundwater in Bangladesh have been published in different local/international journals, daily newspapers, Internet, etc. Moreover, none of them have complete updated information about the source, cause, extent, severity and remedy of the problem. In addition, many of these reports contradict one another.

ARSENIC CONTAMINATION SCENARIO IN BANGLADESH

Arsenic and its Occurrence

Arsenic is a crystal-shape metalloid element which is brittle in nature and greyish white in color. As is a naturally-occurring poisonous chemical element and always occurs as compounds with others. It is widely distributed in the soil profile as component of minerals and found in nominal amounts in all organisms. As can be found as a compound of oxygen, chlorine, sulfur, carbon, hydrogen, lead, mercury, gold and iron. There are as many as 150 species of arsenic-bearing minerals that exist on the earth. However, only few of them are considered as arsenic ore, because the amount of arsenic is higher in these compounds and also they are more available. These compounds are: Realgar or arsenic disulphide (AsS), Orpiment or arsenic trisulphide (As_2S_3) and Arsenopyrite or ferrous arsenic sulphide (FeAsS).

Arsenopyrite has been primarily identified as the main source of arsenic pollution in Bangladesh.

Table 1. Some arsenic-polluted countries with population affected and cause of pollution.

Name of the country	Year	Population affected by arsenic	Maximum range of pollution (mg/L)	Main cause 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	Rive cutting through arsentic-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	1993-2005	30,000,000*	0.052-4.727	Over-exploitation of groundwater (pyrite oxidation) Or arsenic released under reducing condition

Note : '*' Population at risk, actual affected is unknown and '–' data not available
Source : Akram (1997), BGS (1999), SES-DCH (2000) and Rashid and Islam (2006)

Chemically, arsenic compounds are of two types- inorganic and organic. Inorganic arsenic is more toxic (≈10 times) than organic. Inorganic arsenic has again two natural ionic forms- trivalent and pentavalent. The trivalent arsenic (Arsenite, As (III)) is more mobile and toxic (40-60 times) than the pentavalent arsenic (Arsenate, As (V)). As (III) has higher ability to form complex with coenzymes in human and animals. Usually, two types of inorganic arsenic compounds (Arsenite-H_2AsO_3 and Arsenate-H_2AsO_4) and two types of organic arsenic compounds (Methyl arsenic acid-$CH_3AsO_3H_2$ and Dimethyl arsenic acid-$(CH_3)_2AsO_2H$) exist in water. Inorganic Arsenite and Arsenate are commonly found in Bangladesh groundwater (Chappell *et al.,* 1999). Exposure to such high levels of acute arsenic poisoning is very unlikely. However, long-term exposure to very low arsenic concentrations in drinking water is also a health hazard (UN 2001; WHO 2001; Ahmed, 2003; UNICEF 2006).

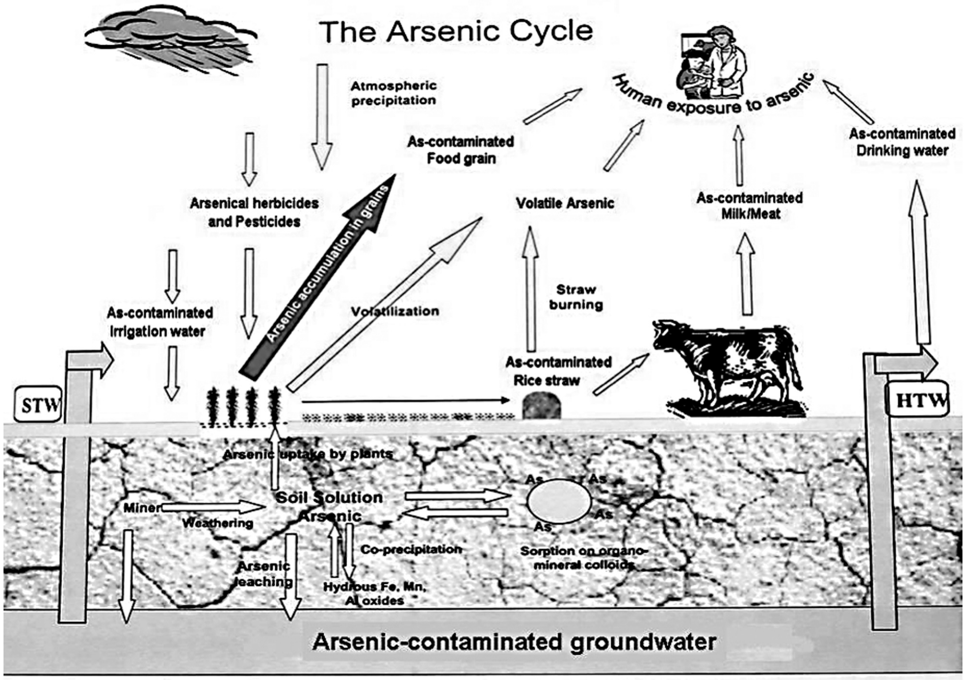

Figure 1. The arsenic cycle in soil-water-plant interfaces (adopted from DPHE, 2000).

Spatial extent of arsenic contamination

DPHE first addressed the As problem in 1993. After that, many government and non-government organizations started working on the problem. Among them, Dhaka Community Hospital (DCH); School of Environmental Studies (SES) of Jadavpur University, India; British Geological Survey (BGS); UNICEF; World Vision; Water Partnership Program (WPP) and DANIDA (official Danish aid agency) are especially mentionable. For every organization, the first job was to identify the arsenic-contaminated wells. According to WHO, the safe limit of arsenic in drinking water is 0.01 mg/L however, the maximum permissible limit for Bangladesh and India at 0.05 mg/L. Sophisticated laboratory facilities are required to accurately detect arsenic in groundwater, but the facilities are very limited in terms of resources and costs in Bangladesh. Therefore, most organizations used field-kit method for As-detection. Field-kit can identify the presence of arsenic with concentration level >0.05 mg/L. It is a Yes-No type field instrument and cannot detect arsenic with reliability if the concentration is <0.2mg/L. Erickson (2003) suggested that field kits used to measure As in the regions' groundwater are unreliable and that many wells in Bangladesh have been labeled incorrectly. To assess the magnitude of As contamination, the World Bank, UNICEF, WHO and several other international aid agencies made a joint decision in 1997 to test all hand-pumped tubewells, using colorimetric field kits. After that more than million of wells were tested in Bangladesh and labeled with red (>0.05 mg/L) and green (<0.05 mg/L) color respectively. However, Rahman et al. (2002) questioned about accuracy and precision of the above methods of test and found that 45% of wells were mislabeled with the observation of a technique called flow injection hydrid generation atomic absorption spectroscopy (FI-HG-AAS). Moreover, As-contamination level changed with time and it was found to become higher in which previously indicated as low level (Erickson, 2003). Table 2 shows the latest survey results of tubewell (TW) water contamination conducted by different stakeholders. It reveals that on average, around 30% drinking water tubewells are As-contaminated in the arsenic-prone areas. Out of 411 surveyed Upazilas, 270 were found to be contaminated, having arsenic above 0.05 mg/L and Upazila-wise contaminated wells range from 0.07 to around 99%. Table 3 and Fig. 2 show the percent of wells contaminated in 61 As-polluted districts, percent area and percent population under each range.

Table 2. Latest survey results of arsenic-affected Upazila (sub-district) by different stakeholders in Bangladesh.

Stakeholder	No. of Upazila*	No. of tube-well (TW)	No. of Safe TW	No. of Contaminated TW	% contaminated TW	
					Average	Range
BAMWSP1	190	3,035,964	214,9846	886,118	29.19	0.19–98.53
Danida	08	159,856	55,700	104,159	65.16	21.17–90.37
UNICIEF	43	1,063,662	739,370	320,710	30.15	1.47–98.62
World Vision	13	227,998	175,927	52,071	22.84	0.08–60.26
WPP[2]	15	215,446	187,462	27,855	12.93	0.07–30.48
JICA[3] & AAN[4]	01	33,344	25,478	7,866	23.59	-
Total	270	4,736,270	3,333,783	1,398,779	29.53	0.07–98.62

Source: Personal collection from DPHE in 2006. * Upazila- sub-district
[1]BAMWSP - Bangladesh Arsenic Mitigation Water Supply Project, [2]WPP- Water Partnership Program
[3]JICA-Japan International Cooperation Agency, [4]AAN-The Asia Arsenic Network

Table 3. Percent (ranges) of arsenic-contaminated tubewells in 61 districts, affected area and population under the contamination (BGS, 2000; Fazal et al., 2001).

% Wells contaminated	No. of districts	Percent area	Percent 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%

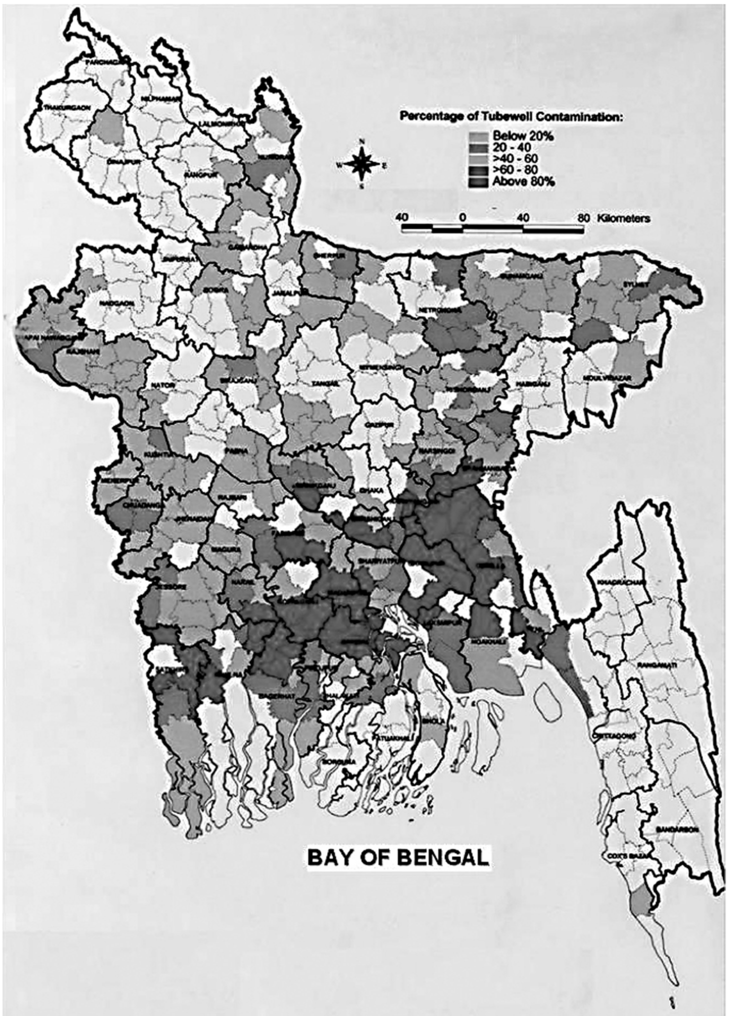

Figure 2. Arsenic Contamination in Bangladesh (adopted from BGS, 1999).

More than 60% of the country is contaminated with arsenic, with more contamination in southern districts. Concentrations of As exceeding 1.0 mg/L of water in shallow tubewells were reported from 17 districts in Bangladesh. The badly-affected districts are Chandpur, Comilla, Noakhali, Feni, Munshiganj, Brahmanbaria, Faridpur, Madaripur, Laksmipur, Gopalganj, Shariatpur, Narayanganj, Sariatpur, Madaripur, Narail, Satkhira and Chapi-Nawabganj. High levels of As have also been found in isolated ‘hot-spots’ in the South-Western, North-Western, North-Eastern and North-Central region of the country (Huq el al., 2006).The Ganges, Megna and Atri rivers floodplains, the tidal regions and coastal plains are the physiographic regions vulnerable to arsenic contamination. In general, where iron (Fe) concentration is higher, As-concentration is also found to be higher. Three hill districts (Rangamati, Khagrachhari and Bandarban, i.e, around 9.0% of total area of Bangladesh) were not surveyed by any organization (Table 3).

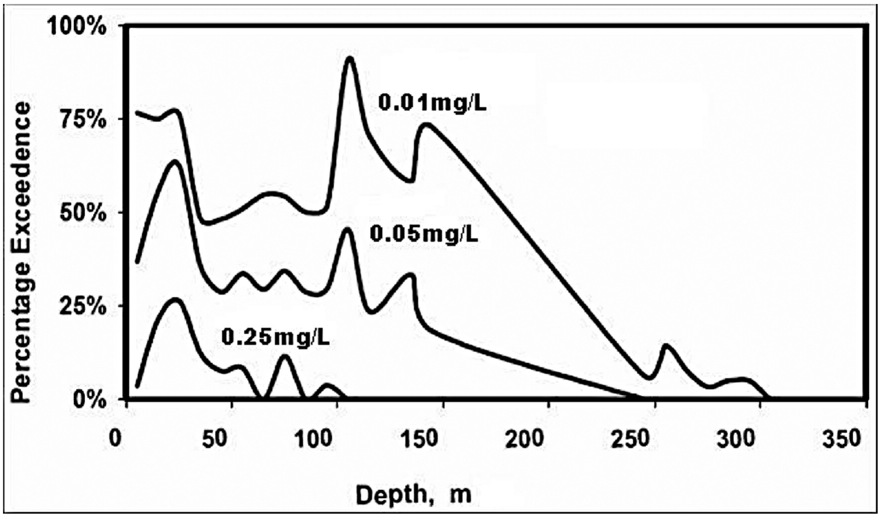

Figure 3. Percentage of wells exceeding specified arsenic contamination at different depth.

Depth-dependent distribution

Several study results show that only the shallow tubewell (STW) and hand tubewell (HTW) water contain high concentration of arsenic. Most of the STWs and HTWs are between 10 m and 70 m deep and high concentration of As is restricted in the upper alluvial sediments, usually at 12-46 m (40-150 ft.) depth. (Fig. 3; Rashid and Karim, 1999). Arsenic levels are low at shallow depths where water is youngest and most affected by pumping, but are also low where water is oldest, deep in the aquifer (Fig. 3). The highest concentrations occur where young and old water appears to be mixed (Harvey et al., 2003). The groundwater flow systems in Bangladesh are complex, and conditions vary due to intensive flash flooding. Natural topographic flow in some areas may control arsenic levels (Aggarwal et al., 2002, 2003), whereas in other stagnant area, i.e, below clay layers, mobilized by detritus of other components (Van Geen et al., 2003). In some areas, irrigation pumping might be flushing arsenic from the systems or introducing oxidants which immobilized arsenic (Harvey et al., 2003).

Population exposed to arsenic threat

BGS (1999) report shows 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 WHO standard (0.01 mg/L) is considered (Fig. 2; Table 2). On the other hand, according to the SES-DCH (2000) report, these numbers are 25 million and 52 million, respectively, out of 85 million people in 43 districts. Therefore, considering all 64 districts, people exposed to arsenic concentrations above 0.05 mg/L may be not less than 36 million (UNECIF, 2006).

Arsenic-related health hazards

Human exposure to arsenic can take place through ingestion, inhalation or skin adsorption; however, ingestion is the predominant form of arsenic intake (IRC, 2007). Arsenic toxicity strongly depends on the form in which arsenic is present. Inorganic arsenic forms, typical in drinking water, are much more toxic than organic ones that are present in sea food. Inorganic arsenic compounds in which arsenic is present in trivalent form are known to be the most toxic. Any form of arsenic compound is toxic to human as well as animal and aquatic products. The toxic effect of arsenic species depends mainly on their chemical form, route of entry, age, sex, dose and duration of exposure. Arsenic toxicity occurs through contaminated food and drinking water (FAO, 2006).

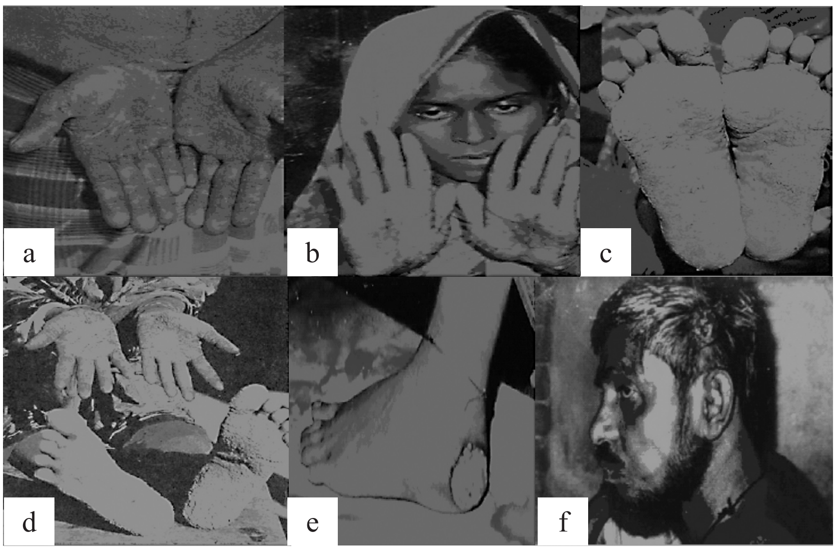

Figure 4. Arsenic-affected diseases in human body (a) Melanosis-palm (b) Melanosis-body (c) Keratosis-sole (d) Keratosis-palm (e) Gangrene-foot-toe and (f) Gangrene-head

Skin diseases are the common effects of arsenic-poisoning melanosis and leuco-melanosis on the palm and body, and keratosis and hyperkeratosis on the palm and sole. Melanosis is not always associated with keratosis, but keratosis is always associated with melanosis. Long-term exposure to excessive arsenic causes changes in skin pigments and hyperkeratosis; promotes development of ulcerations of skin; and accelerates the risk of cancer in liver, lung, bladder, kidney and skin. Arsenical neuropathy and adverse obstetric outcome were also observed (Ahamed et al., 2006).

According to the recent newspaper reports, over 200,000 people in Bangladesh are suffering from arsenic-related diseases, ranging from melanosis to skin cancer and gangrene (Fig. 4). So far 38,000 clear cases of As-patients have been identified. According to WHO (2001), arsenic contamination will cause 200,000-270,000 deaths from cancer in Bangladesh alone. Rural people are more affected than urban people.

Arsenic contamination is not contagious or transferable (Hossain, 2006).

Table 4. Arsenic concentration in hair, nail, skin-scale and urine in arsenic-contaminated areas of Bangladesh (adopted from Rashid and Karim, 1999).

Item	Arsenic content			
	hair (mg/kg)	nail (mg/kg)	skin-scale (mg/kg)	urine (mg/kg)
1. No. of observation	2,167	2,165	220	830
2. Range (mean)	0.28-28.06 (4.05)	0.26-79.49 (9.25)	0.28-23.51 (6.13)	0.024-3.086 (0.495)
3. St. Deviation	24.04	8.73	4.94	0.493
4. % of samples having arsenic at normal level	89	98	-	96
5. Normal level	0.08-0.25	0.43-1.08	Not available	0.005-0.04

It is a matter of great concern that chronic arsenic poisoning due to the use of contaminated groundwater has emerged as a serious health hazard in the country. Table 4 shows the arsenic concentration in hair, nail, skin-scale and urine of patients in arsenic-contaminated areas of Bangladesh (Rashid and Karim, 1999). Some hair samples contain As upto 80 times the normal, nail samples upto 30 times, and urine samples upto 235 times. It was observed that skin test was the most reliable test for detection of arsenic. It was also observed that urine, hair and nail concentrations of As correlated significantly with drinking water As concentrations (Ahamed et al., 2006). The substitution of well water used for drinking and cooking containing 0.10-0.23 mg/L arsenic with water containing 0.003 mg/L arsenic led to a several fold reduction in the As content of urine, nails, and hair (Ali et al., 2003). This was a clear demonstration that the As content of well water is a major factor controlling As exposure and therefore the risk of contracting various As induced diseases in the many areas of South Asia where the rural population relies heavily on groundwater (Smith et al., 2006).

Arsenic in food chain

No doubts that million of households in Bangladesh drink untreated groundwater. Studies of the arsenical problem in Bangladesh have, to date, concentrated on the direct adverse effects of drinking As-contaminated water on human health. Enough attention has not yet been paid to indirect route of exposure to arsenic. With the initiative of Ministry of Agriculture, sporadic research provides disparate information on adverse effect of arsenic on agriculture. Arsenic has been detected in different food items. Long-term use of arsenic-contaminated groundwater to irrigate crops, especially paddy rice (*Oryza sativa*, L.), has resulted in elevated soil arsenic levels in Bangladesh. A green house (pot) study result presented in Table 5, which showed that use of arsenic-contaminated irrigation water decreased seed germination and rice yield, reduced plant height and affected development of root growth (Fig. 4; Abedin et al., 2002).

Table 5. Effect of arsenic-contaminated irrigation water on the agronomic parameters of rice (adopted from Abedin et al., 2002).

As conc. (mg/L)	Plant height (cm)	Tiller number	Root weight (g pot-1)	Straw weight (g pot-1)	Grain number	Grain wt. (g pot-1)	1000 grain weight (g)
0	107	5.7	2.36	17.1	166	3.23	19.49
1	97	7.0	2.04	17.6	128	2.49	19.48
2	99	5.7	1.99	15.5	106	1.94	18.30
4	91	6.3	1.87	15.2	80	1.44	18.04
8	87	4.7	1.69	12.1	68	1.25	18.50

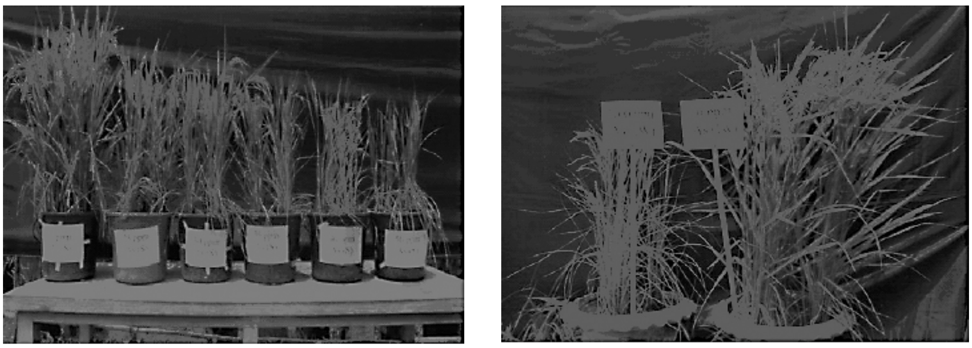

Figure 4. Effect of arsenic-contaminated irrigation water on rice growth stages and yield with different level of arsenic concentration (Personal collection from M. Harun-ur-Rashid, BARI).

The study results also revealed that the arsenic concentration in rice plant parts increased with the increase of As concentration in irrigation water (Fig. 4). However, the remarkable shielding of rice grains from the build-up of As in soil and soil water of paddies irrigated with groundwater is consistent in different studies. The health risks due to ingestion of As contained in rice therefore appears to be dwarfed in countries such as Bangladesh (Van Geen et al., 2006). Moreover, several studies observe that rice (*Oryza sativa,* L.) in different growth stages accumulates As in different levels but at maturing stage uptakes highest amount significantly than at other stages (Fig. 4; Wang, et. al., 2006). Percent of rice seed germination over control decreased significantly with the increasing concentrations of arsenite (As-III) and arsenate (AS-V) and it was found that arsenite was more toxic than arsenate for rice seed germination (Abedin et al., 2002). The impact of using contaminated irrigation water from shallow tubewells indicated the entry of As into human food chain, animal food chain, effect on soil quality, particularly microbiological functioning, and nutrients uptake for production (Hossain, 2006).

Farid et al., (2003) conducted investigation on the effect of arsenic-contaminated irrigation water on 13 vegetables (Fig. 5). Arsenic contents, in general, were found to be higher in the vegetables irrigated with arsenic-contaminated water than those irrigated with arsenic-free water. The trend of arsenic accumulation was higher in leafy vegetables and lower in fruity vegetables. Arsenic levels in rice and vegetable are affected by arsenic contamination of the soil and water in which the food is grown.

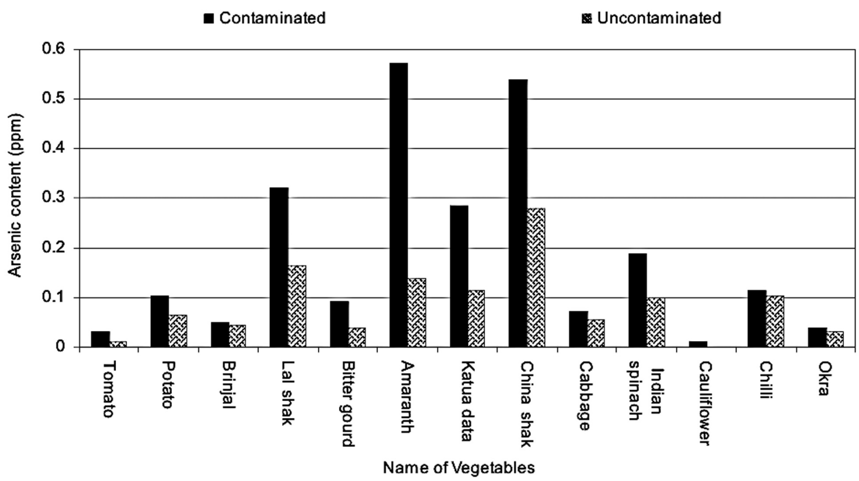

Figure 5. Relative arsenic content of different vegetables irrigated with arsenic contaminated and arsenic-free water (Farid et al., 2003).

Soil arsenic concentrations in Bangladesh range between 4.0-8.0 mg/kg when irrigation water contained 0.01 mg/L arsenic or less. Arsenic concentrations as high as 83.0 mg/kg have been reported in soil when irrigation water contained more than 0.01 mg/L arsenic. Foods grown in arsenic rich soils can absorb the arsenic in the soil (Abedin et al., 2002). To further add to the arsenic burden, it has been demonstrated that arsenic concentrations in rice grain increased significantly with increasing arsenic concentrations in irrigation water. In agreement with Meharg and Rahman (2003), data from a preliminary nationwide survey of As in soil, crops and irrigation water indicate that the soils in the west and southwest part of Bangladesh contain the highest As concentrations (Miah et al., 2005). In these parts, irrigated soils had higher levels of As compared to adjacent non-irrigated soils. In the irrigated soils, the first 0-15 cm had the highest levels of As. In other parts of the country, irrigated and non-irrigated soils did not differ in As concentrations. The differences in soil concentrations were, however, not reflected by As levels in the rice plants. In the 2006 Boro season, a small but detailed pilot study was conducted by BRRI in Faridpur district, in which phytotoxicity to rice was studied at a paddy field which was contaminated by twenty years of irrigation. Preliminary data indicate a clear negative correlation between As in the soil water and plant growth. These results emphasize the need to further investigate the possible risks of As in irrigation water to crop production (FAO, 2006).

Dietary intake of arsenic-contaminated food items by the people is an issue of great concern. Total arsenic intake through daily food should not exceed the permissible limits, where the limit needs to be determined. Therefore, excessive accumulation of arsenic through food could increase the possible threat to human health, if the arsenic is present in an easily-absorbable form. Arsenic content in fodder, its eventual impact on animal health and animal-based food items should receive equal attention (IRC, 2007).

Sources of Arsenic in Bangladesh

Potential source of arsenic contamination may be different in different countries. In Bangladesh, initially several anthropogenic sources were considered for arsenic contamination, such as: i) use of arsenic compounds as preservatives in electric wooden poles of Rural Electrification Board (REB); ii) use of fertilizers (particularly phosphate fertilizers), pesticides, insecticides and herbicides containing arsenic; iii) tubewell filters coated with As-compounds; iv) industrial waste disposal; and v) enhanced leaching beneath irrigated lands (Rashid, 1997; BGS, 1999). Gradually, all these anthropogenic sources were rejected based on the field observations and situation analyses. Finally, it was recognized that the source of arsenic is naturally-occurring geological deposits (Harvey et al., 2002).

Causes of Arsenic Contamination in Bangladesh

Presently, two hypotheses are prevailing to describe the cause (mobilization) of arsenic into groundwater. These are: i) Pyrite Oxidation and ii) 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, the newly-introduced O_2 oxidizes the arsenopyrite in the vadose zone and releases arsenic and arsenic is adsorbed on iron hydroxide. During the subsequent recharge period, iron hydroxide releases arsenic into groundwater. According to this hypothesis, groundwater contamination with arsenic is man-made, which has a relationship with excessive groundwater withdrawal. This is a recent phenomenon. The mechanism is illustrated in Fig. 6.

The pyrite oxidation hypothesis came from West Bengal, a state of India bordering to Bangladesh that has similar geological and environmental factors. West Bengal has also a serious arsenic problem. In West Bengal, it is believed by several authors (Page, 1996; Acharyya, 1997; Roy and Sinha, 1997) that the source of arsenic in groundwater is geological and the cause of contamination is pyrite oxidation.

The intensive irrigation development in the country supports the pyrite oxidation hypothesis. Irrigation development in Bangladesh, using DTWs and STWs, started in the early 1960s and rapidly expanded in the early 1980s. The contribution of groundwater to total irrigated area increased from 41 percent in 1982/1983 to over 75 percent in 2004/05 with an increasing tendency in each year, while the contribution of surface water steadily declined from 59 to <25 percent over the same period (Rashid, 1997; Rashid and Islam, 2006).

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.

This hypothesis was first proposed by Nickson et al., (1998). BGS accepted this hypothesis and considered that groundwater arsenic contamination has no relation with the excessive groundwater withdrawal.

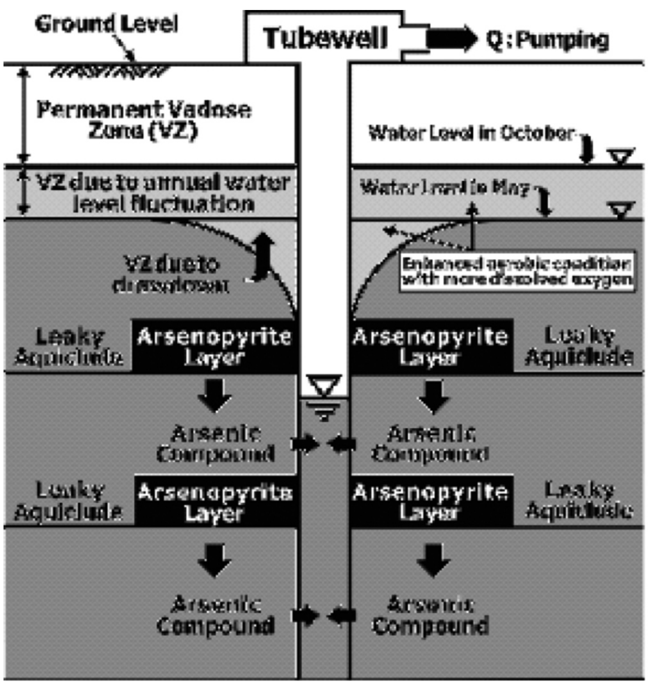

Figure 6. Aerobic condition in groundwater around a tubewell (adopted from Karim *et al.,* 1997).

Remedies of Arsenic Problem

Treatment for arsenicosis

Unfortunately, there is no specific treatment for chronic arsenicosis. A recent report of DCH (2000) states that chronic arsenicosis cannot be cured. But at early stages (upto melanosis), stopping further intake of arsenic-contaminated water, drinking arsenic-free water, and eating of nutritious foods (vegetables, curds, etc.)

improve the cases. Exercise and vitamins (A, E and C) also help, if a patient crosses the threshold limit, 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 and safe drinking water

For a proper remedy of the problem, at first all of the contaminated tubewells should be identified accurately, and then the actual cause(s) of the contamination should be investigated. The over-extraction 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, 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 (PSF) and harvested rainwater, if possible. If no other options exist, it is urgent to shift to surface water use or construct arsenic treatment plants. People in the arsenic-affected areas must be made aware of the hazards of drinking contaminated water and cooking with it.

Disposal of arsenic wastes

Disposal of the arsenic waste must be done very carefully. If the arsenic water is randomly disposed, it can create further havoc by contaminating water sources. The sediment-rich water left at the bottom of the sedimentation-or flocculation-processing container should be poured into cowdung, leaves of arum plant, water hyacinth, cabbage, etc. for detoxification (arsenic is converted into methyl acid, and then evaporates off).

CONCLUSION

i) More than 60% of the country is contaminated with arsenic. About 30 million people are exposed to arsenic poisoning. Thousands of people are suffering from arsenic-related diseases, ranging from melanosis to skin cancer and gangrene, and many even died. Unfortunately, there is no specific treatment for arsenicosis in Bangladesh.

ii) Change of drinking habit and source of drinking water is the chief tool to combat arsenic problem. People in the arsenic-affected areas must be made aware of the hazards of drinking contaminated water and cooking with it. They must drink safe water and eat nutritious foods. If alternate source with safe water is not available, treated water may be used. Sedimentation of contaminated water over night and treatment of contaminated water with copper sulphate (fitkari) can remove arsenic.

iii) 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 and evidence. The verdict is still out rather to support one hypothesis over the other. Experts are divided on the issue.

iv) Arsenic contamination in Bangladesh is a serious national problem. To save the lives of million in Bangladesh, finding the real source and cause(s) of contamination and its mitigation is an urgent need. Then a remedial action plan should be made with participation of experts in relevant fields and community representatives.

v) Though sporadic research detected arsenic in food items, but these isolated tests conducted in very selective areas did not produce any conclusive results on arsenic in food chain.

vi) Research to assess the risk of arsenic poisoning to human/animals through food chain and the impact of arsenic on crop production and soil environment is of paramount importance.

vii) A proper strategic planning and integrated management with holistic approach, taking into consideration both drinking and irrigation water, are urgently required.

viii) Concerted effort/action from all corners and sectors is required to overcome this grave situation.

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