Arsenic Contamination in Bangladesh – an Overview

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Review

Arsenic contamination in Bangladesh—An overview

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Abstract

Bangladesh is currently facing a serious threat to public health, with 85 million people at risk from arsenic (As) in drinking water and in food crops. In Bangladesh, the groundwater As contamination problem is the worst in the world. Ninety-seven percent of the population in the country uses groundwater for drinking and domestic purposes as surfacewater is mismanaged. High levels of As in groundwater are causing widespread poisoning in Bangladesh. Different studies have addressed various aspects of the As issue in Bangladesh. This review is undertaken to give an overview of the latest findings and statistical data on the issue especially on soil, water and food cycle. The World Health Organization (WHO) recommends a safe limit for As in drinking water of 10 $\mu g\ L^{-1}$. A recent survey looked at the As concentrations of drinking water from deep wells in 64 districts in the country and found that 59 had concentrations $>10\ \mu g\ L^{-1}$ and 43 had concentrations $>50\ \mu g\ L^{-1}$. Contaminated groundwater is also used for irrigation of paddy rice, which is the main staple food for the population. This practice enhances the level of As in the soils rendering them unsuitable for agriculture. A few recent studies have reported that 85–95% of total As in rice and a vegetable was inorganic, which outlines the need for more studies for standardization. Arsenic concentration is higher in Bangladeshi soils, groundwater and plants (data based on 4% area of the country) than the permissible limits or normal range reported. This situation poses a serious threat on human and livestock health and highlights the need for scientific studies that would better describes the fate of As in the natural environment and identify all potential routes of exposure.

Keywords: Arsenic (As); Contamination; Soils; Water; Plants

Contents

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1. Introduction

Bangladesh extends between longitudes 88°01′ and 92°40′ east and latitudes 20°25′ and 26°38′ north. Geographically, Bangladesh consists of the great flood plain of the Bengal Delta bordered by the Himalaya–Arakan–Yoma mountain range complex in the north and east. Bangladesh is a densely populated country with 128 million people (Bangladesh Bureau of Statistics, BBS, 1998) living in a comparatively small area of 147,570 km^2 (867 persons km^2). Furthermore, it has a high population growth rate of 1.8% per annum (BBS, 1998). The country is now well known as a land of natural calamities where flood and drought are recurrent phenomena. In addition, As contamination has recently been identified as the single biggest threat to Bangladeshi groundwater sources. The problem is gradually taking alarming proportions.

The extent and severity of the water crisis is well known in areas such as the Middle East, India and Bangladesh. Freshwater quality will become the principal limiting factor for sustainable development in many countries early in this century (Ongley, 1999). An ancient quotation from Anon. (1977) saying that "Everything living is created from water", accurately describes the importance of water. Humans have been concerned with water from the very beginning of their existence. The quantity of water on earth appears enormous when it is considered that more than two-thirds of Earth's surface is covered with water. However, 97.2% is seawater, 2.05% is frozen water and only 0.65% is freshwater on land and/or in the atmosphere (Anon., 1977). Over 98% of available global freshwater is stored as groundwater in the saturated zones within pores and fractures in rocks (Hiscock, 1994; Jones, 1997). Consequently, groundwater comprises a significant proportion of the water resources in most countries. Similarly, groundwater accounts for 97% of rural drinking water supplies and irrigation source in Bangladesh (UNICEF, 2001; WHO, 2001). Groundwater often provides a water supply that is more reliable in quantity and more stable in quality than surfacewater and thus has economic and operational advantages due to reduced treatment requirements (Robins, 1990).

Following independence, the governments of Bangladesh assisted by aid agencies, have provided most of the population with safe drinking water by installing tube wells that extract water from subsurface alluvial aquifers. This achievement has reduced the incidence of waterborne diseases but only to replace it with another problem: groundwater contamination by As. The As problem has been reported in many countries, with the most severe occurring in Asia, especially Bangladesh (Chowdhury et al., 1999; Biswas et al., 1998; Nickson et al., 1998, 2000; Dhar et al., 1997; Khan and Ahmad, 1997). The presence of As in groundwater above the World Health Organization (WHO) standard was first detected in 1993–1994. While the provisional WHO guideline for drinking water was 10 $\mu g\ L^{-1}$, the national standard value in Bangladesh was five times higher (<50 $\mu g\ L^{-1}$). In some areas of Bangladesh, it was reported that groundwater As concentrations reached up to 2000 $\mu g\ L^{-1}$ (Tondel et al., 1999; BGS, 2000; Erickson, 2003). During the same period, the Department of Public Health Engineering (DPHE) also found that 1.2 million tube wells out of 3–4 millions (29%) were contaminated with As. The issue really became known at the beginning of 1995, although the awareness had started earlier in 1993. In 1999, the British Geological Survey (BGS) and DPHE identified that the groundwater of 60 survey districts out of 64 was contaminated with As, which had also high levels of uranium, manganese, boron, sulphur, fluoride, molybdenum, barium and phosphate. Four districts—Khagrachari, Rangamati, Banderban and Cox's Bazar have not been surveyed yet.

A survey from the School of Environmental Studies and Dhaka Community Hospital source said that 47 districts are contaminated with As, which represents a total of 241 villages where As patients are suspected, thousands are currently As patients and a total of 40 deaths due to As related diseases. According to this source of the DPHE, 3571 out of 109,022 deep tube wells that can supply safe drinking water are now out of order. In addition, 45,025 out of 1,057,267 hand pumped tube wells are inoperative. Alternatively, arrangements for safe drinking water in the affected areas, provided by the government, are mostly insignificant and confined to few families. Although the government encourages use of surfacewater, and water from wells, people find it inconvenient and revert to the tube well water despite As contamination. At this point, the exact severity of As pollution is unknown. ''The fact is that the government machinery has no system to determine the number of As-contaminated tube wells. They are just relying on estimates that have no relevance''. Although the government has a plan to survey all the tube wells supplying drinking water, the task has not been completed yet.

Numerous scientific papers (Ahmed et al., 2005, 2004; Horneman et al., 2004; Zheng et al., 2004; van Geen et al., 2003; Harvey et al., 2002; Fazal et al., 2001a,b; Karim, 2000; Kamal and Karim, 2000; Begum and Karim, 2000; Hossain et al., 2000; Adel, 2000; Bridge and Husain, 1999, 2000a,b; Karim and Badruzzaman, 1999; Chowdhury et al., 1999; Kamal et al., 1999; Nickson et al., 1998, 2000; Khalequzzaman, 1999; Ullah, 1998; Karim et al., 1997) and many organizations (DCH, 1997; BGS, 1999; DPHE/BGS/DFID, 2000) have implemented different As programs and revealed the extent and severity of the problem. To date, different issues such as population exposed to contaminations, assessment and modeling of As transport, As mobility and groundwater extraction, cause of contamination and number of people suffering from arsenosis have been addressed. The World Bank is currently taking the lead in coordinating an integrated response to the arsenic crisis and through the GOB is supporting the Bangladesh Arsenic-Mitigation Water Supply Project (BAMWSP). A key component of the BAMWSP is community-based, demand driven projects, in which community members play an active role in choosing and implementing solutions to the site-specific problems of arsenic contamination. However, no one has devised practical methods of groundwater remediation, most studies and actions have focused on testing tube well water for arsenic. Recently, in the coastal areas (17% of Bangladesh surface), the DPHE-Danida water supply and sanitation project has started to provide safe water outlets for the poorest of the poor and management of the project has been entrusted with the local communities.

The objective of the current manuscript is to present the most up-to-date overview of the As contamination in Bangladesh with special emphasis of soil, water and food cycle.

2. Procedure

The scientific literature was systematically searched from the first identification to the present for information on As research practices, mostly based on Bangladesh. The search was carried out using the West Bengal and Bangladesh arsenic crisis information center. The National Research Council's CISTI source (a collection of 14,000 scientific journals) was also searched electronically. In addition, various conference dealing with arsenic crisis were surveyed and personal contacts were made with key authors. On the basis of the titles and abstracts, the original papers were obtained and cited. Any relevant references cited in these papers were also obtained for review. Several current research program leaders on As research to mitigate related to the Bangladesh issue were contacted to obtain information on specific problem and the long-term solution for As issues in Bangladesh.

3. Occurrences and nature of arsenic

Arsenic is ubiquitous in the environment, which occurs in both solid and liquid phases, exhibits both metallic and non-metallic properties and cannot be found in nature in native state (Train, 1979). Arsenic is usually present in all rocks, soils, waters, air and biological tissues, and is primarily produced as a by-product from smelting Cu, Zn, Pb, Hg, Au and other ores (Nriagu and Pacyna, 1988). In nature, there are 150 species of As bearing minerals, however, only 3 of them, i.e., As sulphide or realgar (As_2S_2), As tri-sulphide or orpiment (As_2S_3) and arsenopyrite or ferrous As sulphide ($FeAsS_2$) are considered as As ore because the amount of As is higher in these three compounds. In Bangladesh, arsenopyrite has been identified as the prime source of As pollution (Fazal et al., 2001a). Arsenic has been recognized as a toxin and can be carcinogenic depending on its chemical and physical forms, concentration and duration of exposure. Chemically, it exist as organic and inorganic species. Inorganic As has two main oxidation states, i.e., trivalent [arsenite, As(III)] and pentavalent [arsenate, As(V)]. Arsenite is 60 times more toxic than arsenate (Fazal et al., 2001b). Inorganic forms of As dissolved in drinking water are the most significant forms of natural exposure. Organic forms of As present in food are much less toxic to humans. Clinical manifestations of As poisoning begin with various forms of skin disease, and progress via damage to internal organs ultimately to cancer and death.

4. Geological source of As according to BGS (2000)

While it is possible that some anthropogenic sources may explain isolated cases of As contamination, none of the anthropogenic explanations can account for the regional extent of groundwater contamination in Bangladesh. There is no doubt that the source of As is geological. There have been insufficient analyses of the alluvial sediments to provide a regional picture but current data suggest that As is usually in the range 2–20 mg kg^{-1}; only slightly greater than typical sediments (2–6 mg kg^{-1}). However, it appears that an unusually large proportion of the As is present in a potentially soluble form. The high groundwater As concentrations are associated with the gray sands rather than the brown sands.

There is a good correlation between extractable iron and arsenic in the sediments and a relatively large proportion (often half or more) of the arsenic can be dissolved by acid ammonium oxalate, an extractant that dissolves organically bound Al and Fe as well as hydrous ferric oxide and other poorly ordered oxides. This correlation suggests that a high proportion of As in the sediments is present as adsorbed species.

The greatest As concentrations are mainly found in the fine-grained sediments especially the gray clays. A large number of other elements are also enriched in the clays including iron, phosphorus and sulphur. In Nawabganj, the clays near the surface are not enriched with arsenic to any greater extent than the clays below 150 m—in other words, there is no evidence for the weathering and deposition of a discrete set of As-rich sediments at some particular time in the past. It is not yet clear how important these relatively As-rich sediments are for providing As to the adjacent, more permeable sandy aquifer horizons. Likely, no simple relationships are found between the As content of the sediment and that of the water passing through it (BGS, 2000).

The BGS (2000) also reported that the original sources of arsenic existed as both sulphide and oxide minerals. Oxidation of pyrite in the source areas and during sediment transport would have released soluble arsenic and sulphate. The sulphate would have been lost to the sea but the arsenic, as As(V), sorbed by the secondary iron oxides formed. These oxides are present as colloidal-sized particles and tend to accumulate in the lower parts of the delta. Physical separation of the sediments during their transport and reworking in the delta region has resulted in a separation of the arsenic-rich minerals. The finer grained sediments tend to accumulate in the lower energy parts of the delta, which might explain the greater contamination in the south and east of Bangladesh. The map of As-contaminated groundwater shows that highly contaminated areas are found in the catchments of the Ganges, Brahmaputra and Meghna rivers, strongly suggesting that there were multiple source areas for the As contamination (Fig. 1).

5. Causes

According to BGS (2000), the groundwater As problem in Bangladesh arises because of an unfortunate combination of three factors: a source of As (As is present in the aquifer sediments), mobilization (As is released from the sediments to the groundwater) and transport (As is flushed in the natural groundwater circulation). Two prevailing hypotheses to describe the mobilization of As into groundwater in Bangladesh are: (1) pyrite oxidation and (2) oxy-hydroxide reduction (Fazal et al., 2001b; Zheng et al., 2004; Horneman et al., 2004).

5.1. Pyrite oxidation hypothesis

Arsenic is assumed to be present in certain sulphide minerals (pyrite) that are deposited within the aquifer sediments. Due to the lowering of water table, the oxidation of arseno-pyrite in the vadose zone releases As and As can be readsorbed on Fe hydroxide during the subsequent recharge period, the reduction of Fe hydroxide releases As into groundwater. In accordance with the hypothesis, the origin of As-rich groundwater is man-made, and would be a recent phenomenon (Karim et al., 1997).

The intensive irrigation development in Bangladesh supports the above hypothesis. The development of irrigation in Bangladesh started in 1960s using shallow tube wells and deep tube wells and rapidly expanded in the early 1980s. At first deep tube well irrigation became very popular in the country because the GOB subsidized farmers to purchase deep tube wells. Under the privatization policy of the government and in accordance with World Bank suggestion since 1991, the GOB stopped such subsidies to the farmers. As a result, deep tube well irrigation development became stagnant after 1991, and shallow tube wells gained popularity due to the lower cost and withdrawal of rules and regulations on tube well installation by the GOB under the new privatization policy. During the irrigation seasons between 1995 and 1997, the area under shallow tube wells increased 7.7%. The areas irrigated by deep tube wells, low life pumps and the traditional system decreased by 11.7, 1.2 and 20%, respectively. As a result, the overall area under the minor irrigation increased by 1%. During this period, the area irrigated by groundwater increased by 3.1%, while the area by surfacewater decreased by 3.8%. The contribution of groundwater to the total irrigated area increased from 41% in 1982–1983 to 71% in 1996–1997 with an increasing tendency. In contrast, surfacewater irrigation steadily declined from 59 to 29% over the same period (NMIDP, 1998).

The lack of reported cases of As related disease before groundwater-based irrigation development in the country also supports the pyrite oxidation hypothesis. Until two years ago, groundwater in Rangpur, Bogra and Jamalpur districts had been considered as safe. Now not only are these areas ensuring As contamination in groundwater, many cases of As related diseases have also been identified.

5.2. Oxy-hydroxide reduction hypothesis

According to this hypothesis, the origin of As-rich groundwater is due to a natural process. The As in groundwater has been present for thousands of years without being flushed from the delta. This oxy-hydroxide reduction hypothesis was first proposed by Nickson et al. (1998) and later supported by Fazal et al. (2001b), Zheng et al. (2004) and Horneman et al. (2004). Arsenic is assumed to be present in high concentrations in alluvial sediments of sand grains coated with iron hydroxide. The sediments were deposited in valleys eroded in the delta when the stream base level was lowered due to the drop in the sea level during the last glacial advance. Following upraise in the sea level, these sediments stream submerged and reduced. The reducing

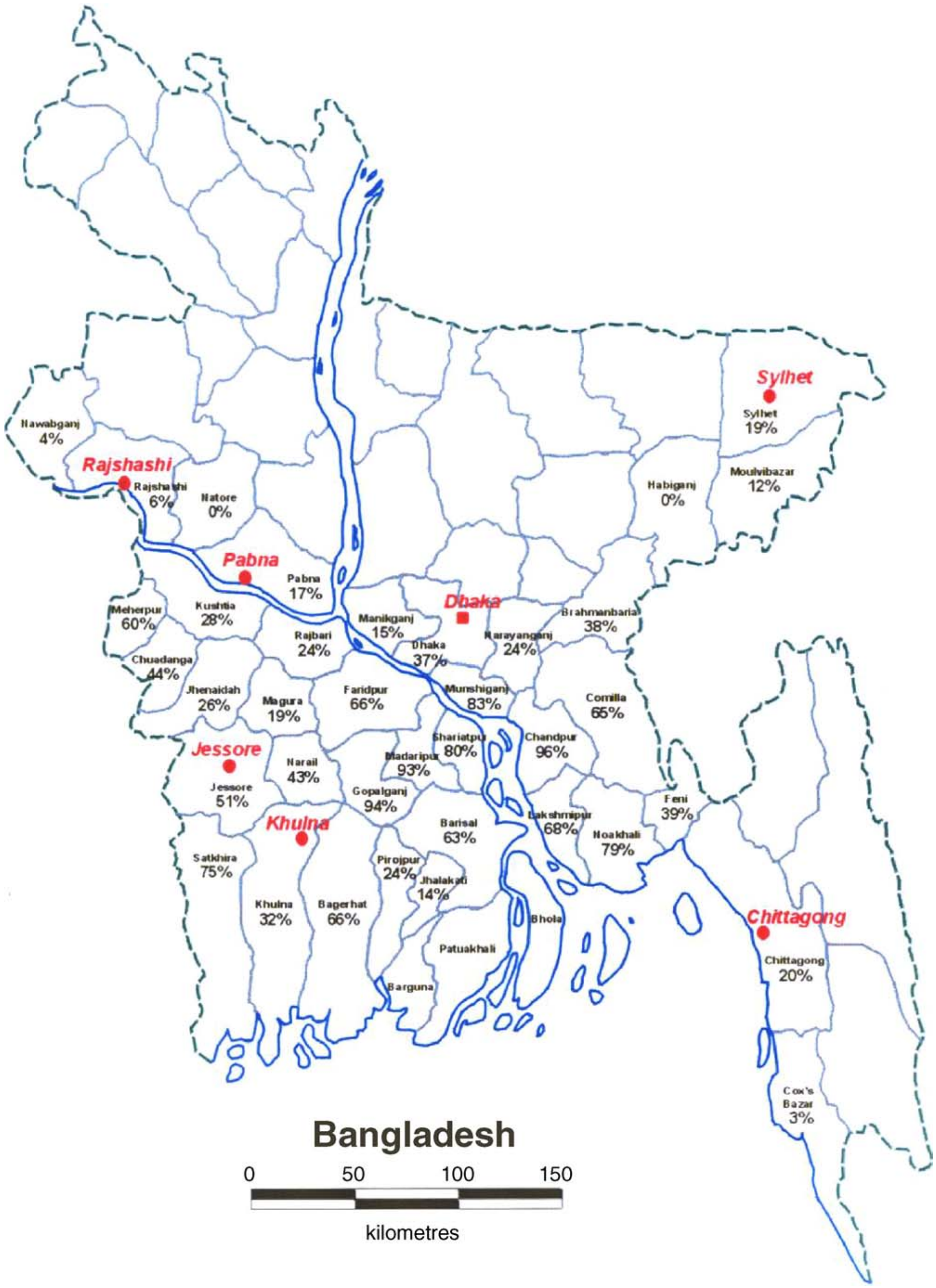

Fig. 1. Percentage of groundwaters from the shallow aquifer (less than 150 m deep) exceeding the Bangladesh standard for arsenic of 0.05 mg L^{-1}.

conditions would be enhanced by the organic matter deposited with the As bearing Fe hydroxide sediments and would lead to As solubilization into groundwater.

6. Distribution

There is a strong correlation between the occurrence of As and the surface geology and geomorphology. The worst affected aquifers are alluvial deposits beneath the recent floodplains (Ganges, Tista, Meghna and Brahmaputra). Older sediments beneath the Barind and Madhupur Tracts and the eastern hills and their adjoining piedmont plains are not significantly affected by As. There are also important differences with the floodplains. The floodplains of the Brahmaputra and the Tista rivers in the north of the country show the lowest levels of contamination. The most affected aquifers lie beneath the Meghna floodplains of southeast Bangladesh. The Ganges floodplains, which have been the most extensively sampled, show the greatest spatial variability. The distribution of As in groundwater of Bangladesh is shown in Fig. 1 (BGS, 1999).

6.1. Arsenic in soils

In the biosphere soil is a very important component because it is not only a geochemical sink for contaminants but also acts as a natural buffer controlling the transport of chemical elements and substances to the atmosphere, hydrosphere and biota. The most important role of soil is its productivity, which provides for basic need for the survival of humans. Arsenic is distributed rather uniformly in major types of rocks—soils and its common concentrations in most rocks range from 0.5 to 2.5 mg kg^{-1} and contaminated soils from 10 to 2470 mg kg^{-1}.

In Bangladesh, very few soil analytical works have been done on As issue. Uddin (1998) of Dhaka University reported that the mean As concentration in uncontaminated agricultural soils in some districts of Bangladesh varied between 2.6 and 7.6 mg As kg^{-1} (mean 4.64 mg As kg^{-1}) (Table 1), which is comparable to the standard level of As in other uncontaminated soils from various countries ranging from 0.1 to 40 mg kg^{-1} (mean 6 mg kg^{-1}) (Mandal and Suzuki, 2002). A similar range of 0.5–25 mg kg^{-1} was reported by Kabata Pendias and Pendis (1992) for As content of surface soils from different countries.

In contrast, soil As in some Bangladesh areas where irrigation is carried out with As contaminated groundwater, soil As level can reach up to 83 mg kg^{-1} (Ullah, 1998). This As content falls in the reported range of 10–2470 mg As kg^{-1} for soils contaminated by pesticides wastes or industrial activity (Kabata Pendias and Pendias, 1992; Mandal and Suzuki, 2002). Alam and Sattar (2000) reported that elevated As concentrations up to 57 mg kg^{-1} in Bangladesh soils collected from different locations could lead to elevated concentrations of As in rice grain and rice straw, which is used to feed cattle's and cows. A detailed As survey in soils of Bangladesh has been done by BGS (1999), and is presented in Fig. 2.

Table 1
Concentration of As in uncontaminated agricultural surface soils (0–15 cm depth) of Bangladesh

Districts	No. of samples	Ranges of As (mg kg^{-1})	Mean of As (mg kg^{-1})
Dhaka	20	1.70–4.11	2.55
Gazipur	15	1.13–5.20	3.13
Khulna	10	3.10–7.16	5.13
Satkhira	12	2.50–6.73	5.50
Meherpur	15	2.15–7.32	4.68
Kustia	15	3.62–8.60	7.25
Jhenaidah	10	1.95–7.15	3.57
Jessore	12	4.35–9.12	7.50
Rajshahi	15	1.65–6.32	3.80
Nawabganj	15	2.11–7.15	4.11
Mona bridge	10	4.35–8.10	4.35
Pabna	15	4.85–9.13	7.60
Narayanganj	10	2.78–3.83	3.29
Sonargaon	15	3.95–7.35	5.76
Comilla	10	1.96–4.44	3.30
Laksam	10	2.17–3.85	2.80
Lakshmipur	10	3.36–3.05	2.61
Faridpur	15	2.36–12.60	6.62
Total	234		4.64[a]

[a] Mean.

6.2. Arsenic in plants

As is an element of most plants, which is found to be cumulative in living tissue, i.e., once ingested by any organism it is passed out of the organism only very slowly if at all. The amount of As in a plant, depends almost solely on the amount of As. Its concentration varies from less than 0.01 to about 5 μg g^{-1} (dry weight basis) (Mandal and Suzuki, 2002). There appears to be little chance that animals will be poisoned by consuming plants which absorb As residues from contaminated soils, because plant injury occurs before toxic concentrations can appear. The As taken up by various plant species, that As was translocated within the plant since its concentration in the grain was detectable. With increasing soil As concentrations, however, the highest As concentrations were always recorded in old leaves and in roots (Kabata Pendias and Pendias, 1992). Concentrations of As in plants grown on uncontaminated soils vary from 0.009 to 1.5 mg kg^{-1}, with leafy vegetables having the higher concentrations, and fruits the lower concentrations (Table 2).

One doctoral research on As accumulation in paddy soils, grain and straw has been done using greenhouse experimental methodology (Abedin, 2002) and one M.Sc. thesis reported rice plants, grains, grass, mustard plants and Amaranthus As contents from As contaminated area at four locations in Bangladesh (Uddin, 1998). Both reported that paddy rice (*Oryza sativa* L.) the main staple food of Bangladesh, is also contaminated with As because the same groundwater that is used for drinking is used for irrigation of crops. Over time, the paddy soils become contaminated with As, particularly in areas with highly contaminated groundwater. Unfortunately, Bangladesh is far from being alone. High levels of As have also been found in groundwater in other areas in southeast Asia including China, Vietnam and Thailand, where rice is also a staple food. However, it is unclear whether the As in rice is in a form that is bioavailable.

6.2.1. Main crops in Bangladesh

The people of Bangladesh not only drink the As contaminated groundwater, but also irrigate their crops with this water. Nearly, 100 different types of crops are currently grown in Bangladesh, but rice is the principal crop in all-growing seasons. Rice crop accounts for 80% of the total cropped area (14.3 million ha) and needs a huge quantity of water especially during the dry season (Dey et al., 1996; BBS, 1998; Hossain, 2001; Hossain et al., 2005). Two main reasons for this are: (i) the very high demand for rice as the staple food and (ii) government agricultural policy. Other important crops grown include wheat, jute, potato, oilseeds, pulses, tobacco, cotton,

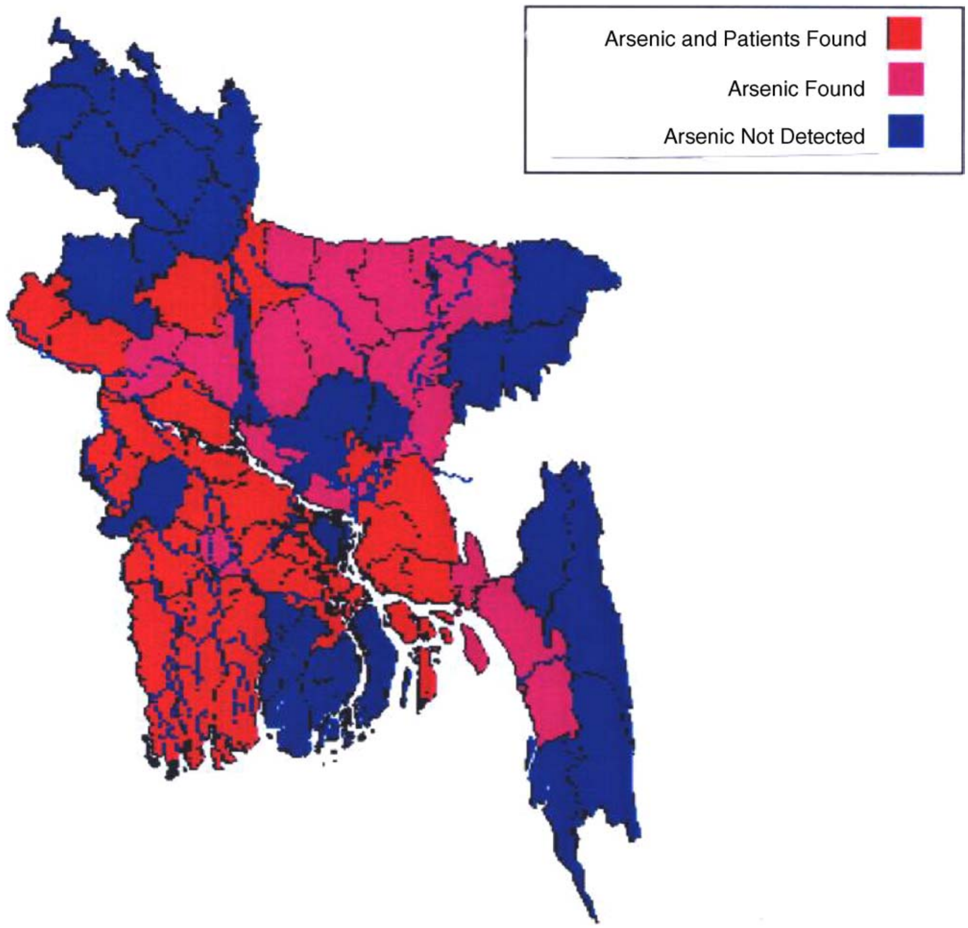

Fig. 2. Arsenic contaminated areas in Bangladesh (*Source*: Jakaria, 2000).

sugarcane and vegetables. Although rice crops in Bangladesh are grown both under rain-fed and irrigated conditions, rain-fed agriculture is dominant, with more than 70% of the net cultivable area being dependent on rain, as the primary source of water for crop production. Thus, irrigated agriculture is limited to less than 30% of the net cultivatable area in Bangladesh. Increased crop production is largely dependent on the expansion of irrigated agriculture based on shallow or deep tube wells (Hossain, 2001).

Table 2
As content of food and forage plants ($\mu g\ kg^{-1}$) (Kabata Pendias and Pendias, 1992)

Plants	Tissue sample	Dry weight basis
Rice	Grains	110–200
Wheat	Grains	50, 3–10
Barley	Grains	3–18
Oats	Grains	10
Corn	Grains	30–400
Beans	Pods	7–100
Cabbage	Leaves	20–50
Spinach	Leaves	200–1500
Lettuce	Leaves	20–250
Carrot	Roots	40–80
Onion	Bulbs	50–200
Potato	Tubers	30–200
Tomato	Fruits	9–120
Apple	Fruits	50–200
Orange	Fruits	11–50
Edible mushroom	Whole	280
Clover	Tops	20–160

Addition of phosphate can enhance downward movement of As leading to increased leaching from the top soil (Davenport and Peryea, 1991; Peryea, 1991; Peryea and Kammereck, 1997), and increase availability of As in the soil solution, which facilitates higher As uptake by the plants (Creger and Peryea, 1994). In the Abedin et al. (2002a) study, the use of As-rich irrigation water reduced plant height, decreased rice yield and affected development of root growth, while As concentrations in all rice plant parts increased with increasing arsenate concentration in the irrigation water. However, for Bangladesh As concentration in rice grain did not exceed the maximum permissible limit of 1.0 mg kg^{-1}. Arsenic did accumulate in rice straw at very high level (up to 91.8 mg kg^{-1}) and this level was the same order of magnitude as root As concentrations (up to 107.5 mg kg^{-1}). These results suggested that feeding cow and cattle with such contaminated straw and root could be a direct threat for their health and also an indirect threat to human health via presumably contaminated bovine meat and milk (Abedin et al., 2002b).

6.3. Phytotoxicity

Arsenic in plant tissue, arsenic accumulates in animal tissue, allowing for a wide variation in concentration due to the variance in As ingested in different areas. Several plants species are known to tolerate a high level of As in tissues. As toxicity has commonly been noted in plants growing on mine waste, on soil treated with arsenical pesticides and on soils enriched with As by sewage sludge treatment (Kabata Pendias and Pendias, 1992). Leaf wilting, violet coloration (increased anthocyanin), root discoloration and cell plasmolysis are the main As toxicity symptoms. However, the most common symptom is growth reduction. Rice grown on apple orchard soil containing 77 mg kg^{-1} As produced almost no yield in the first year. In the same study, the toxic effect of As was partly reduced in the third year of cultivation without any special treatment but an application of S greatly reduced the phytotoxicity of As (Kitagishi and Yamane, 1981). There are some reports of the stimulating effects of As on the activity of soil microorganisms, As is known as a metabolic inhibitor. Therefore, under a high level of bioavailable As yield reduction of vegetation should be expected and As would be less toxic when the plant is well supplied with P (Kabata Pendias and Pendias, 1992).

Plants may accumulate extremely large amounts of As depending on the location and pollution source (Table 3). The highest concentration 8000 mg kg^{-1} was reported in Douglas fir tree in growing on mining sites in Canada. Although As poisoning from plants to animals is believed to be very uncommon, unfavorable health effects of a high As concentrations in vegetables and forage plants cannot be precluded.

Arsenic concentration in Bangladeshi plants varies with the parts of a plant. Distribution of As in the stem of potatoes is higher that in leaves; in arum: leaves and stem contains more As than root; in kalmi sak (a vegetable): As in leaves > As in stem; in paddy rice (*O. sativa* L.): root > stem > rice. Although food chain contamination has not been firmly established, some trends of As contamination through localized groundwater source in plants could be considered (Das et al., 2003). A detailed soil, water and plant chain study on As contamination in Bangladesh is greatly needed.

6.4. Arsenic in water (ground, surface and river) (Tables 4–6)

Four main species of As occur in water: inorganic forms such as arsenite ($H_2AsO_3^-$) and arsenate ($H_2AsO_4^-$), which are commonly found in the Bangladeshi groundwater and organic forms such as methyl arsenic acid [$CH_3AsO(OH)_2$] and dimethyl arsenic acid [$(CH_3)_2As(OH)$] (Fazal et al., 2001b).

High levels of As in water lead to health problems, such as melanosis, leuko-melanosis, hyperkeratosis, black foot disease, cardiovascular disease, hepatomegaly, neuropathy and cancer (Khan and Ahmad, 1997). As tends not to accumulate in the body but is excreted naturally. If ingested faster than it can be excreted, As accumulates in the hair and fingernails. As toxicity varies with the chemical and physical forms of the compound, the route by which it enters the body, the dosage and the duration of exposure, dietary compositions of interacting elements, the age and sex of the exposed individuals.

With regard to manifestation in a person's body, the symptoms of arsenic toxicity may take several months to several years to build up. This period differs from person to person, depending on the quantity and volume of arsenic ingested, nutritional status of the person, immunity level of the individual and the total time period of arsenic ingestion (DCH, 1997). Malnutrition and poor socio-economic conditions aggravate the hazards of As toxicity. Although arsenicosis is not an infectious, contagious or hereditary disease, As toxicity creates many social problems for the victims and their families (Khan and Ahmad, 1997; Jakaria, 2000).

There is a need to know more about the impact of arsenic poisoning on human health. For instance, there is no clear understanding of why some members of a family or community are affected, while others in the same family or

Table 3
Excessive levels of As in plants grown in contaminated sites (mg kg^{-1}) (*Source*: Kabata Pendias and Pendias, 1992)

Site and pollution source	Plant and part	Mean/range	Country
Mining or mineralized area	Douglas fir, stems	140–8200	Canada
	Grass, tops	460–6640	UK
Metal processing industry	Grass	0.5–62	Canada
	Tree foliage	27–2740	Canada
	Rice, leaves	7–18	Japan
	Hay	0.30–2.6	Norway
Battery manufacturer	Tree, foliage	16–387	Canada
Sludge or irrigated fields	Brown rice	1.2 (maximum)	Japan
Application of arsenical pesticides	Turnip, roots	1.08	Canada
	Potato, tuber peels	1.10	Canada
	Carrot, roots	0.26	Canada

Table 4
An overview of As concentration in groundwater of Bangladesh (Chowdhury et al., 1999; BGS, 2000)

Total area (km^2)	147570
Total population (m)	128
Total no. of districts	64
No. of districts not yet been surveyed	4
No. of district where As <10 $\mu g\ L^{-1}$	8
No. of district where As 10–50 $\mu g\ L^{-1}$	11
No. of district where As >50 $\mu g\ L^{-1}$	41
Total area of the districts where As >50 $\mu g\ L^{-1}$ (km^2)	89186
Total population of districts where As >50 $\mu g\ L^{-1}$ (million)	85

Table 5
Concentration of As in tube well water in 60 districts of Bangladesh (Chowdhury et al., 1999; BGS, 2000)

Total number of tube well water samples analyzed	9089
Number of tube well samples in different concentration range ($\mu g\ L^{-1}$) of As	
<10	3507 (38.59%)
10–50	1459 (16.05%)
>50	4123 (45.36%)
>1000	189 (2.08%)

Table 6
Analytical report of 41 districts of Bangladesh where As found in groundwater >50 $\mu g\ L^{-1}$ (BGS, 2000; Chowdhury et al., 1999)

Districts	No. of thanas	No. of thana surveyed	No. of thanas where As ($\mu g\ L^{-1}$)		No. of samples	Samples in different As concentration ($\mu g\ L^{-1}$) range							
			>10	>50		<10	10–49	50–99	100–299	300–499	500–699	700–1000	>1000
Nawabganj	5	5	4	4	622	184	99	48	173	53	32	9	24
Rajshahi	13	5	3	2	315	249	55	8	3	–	–	–	–
Pabna	9	9	8	5	354	204	61	19	36	15	6	5	8
Kustia	6	5	5	5	292	128	101	22	14	9	4	4	10
Meherpur	2	1	1	1	79	7	12	19	32	8	1	–	–
Chuadanga	4	4	3	2	28	5	4	2	4	6	6	1	–
Jinaidah	6	1	1	1	26	10	9	3	2	1	–	1	–
Jessore	8	5	5	5	665	113	75	219	162	44	31	19	2
Sathkira	7	4	4	4	156	28	53	23	41	7	3	1	–
Khulna	14	7	7	6	862	484	185	66	93	25	7	2	–
Bagerhat	9	3	3	3	188	18	24	19	57	47	13	10	–
Narayanganj	5	2	2	2	188	48	5	2	54	28	24	17	10
Faridpur	8	3	3	3	324	64	97	36	79	21	14	5	8
Rajbari	4	3	3	2	70	35	27	3	4	–	–	1	–
Magura	4	2	2	2	34	14	13	2	2	–	1	1	1
Chandpur	7	4	4	4	211	3	6	14	54	106	23	3	2
Noakhali	6	4	4	4	198	3	4	11	53	27	30	16	54
Lakshmipur	4	4	4	4	1326	45	109	173	405	223	175	127	69
Munshiganj	6	4	4	4	123	10	6	11	61	29	6	–	–
Madaripur	4	3	3	3	80	2	14	16	23	15	7	3	–
Sariatpur	6	4	4	3	70	30	19	8	6	6	1	–	–
Narail	3	2	2	2	32	19	10	2	1	–	–	–	–
Barisal	10	4	4	4	116	24	12	15	48	11	3	3	–
Pirojpur	6	3	3	3	65	35	15	3	10	2	–	–	–
Jhalakhati	4	3	3	2	28	17	6	2	2	1	–	–	–
Gopalganj	5	3	3	3	98	18	23	9	20	13	7	8	–
Natore	6	3	3	1	109	91	14	3	1	–	–	–	–
Comilla	12	4	3	3	135	14	1	1	24	54	33	8	–
Manikganj	7	3	3	3	116	43	22	26	25	–	–	–	–
Feni	5	2	2	1	30	5	18	4	3	–	–	–	–
Narsingdi	6	3	2	2	163	87	10	9	23	23	8	2	–
Chittagong	20	13	6	2	283	243	20	8	12	–	–	–	–
Sherpur	5	2	2	2	52	39	7	2	4	–	–	–	–
Netrokona	10	2	2	1	29	24	2	3	–	–	–	–	–
Mymensingh	12	3	3	2	49	30	17	2	–	–	–	–	–
Jamalpur	7	2	1	1	39	23	6	4	6	–	–	–	–
Tangail	11	2	1	1	10	9	–	1	–	–	–	–	–
Kishoreganj	13	2	2	2	78	31	28	12	7	–	–	–	–
Sunamganj	10	2	2	2	34	4	14	12	4	–	–	–	–
Sirajganj	9	4	3	2	42	18	21	3	–	–	–	–	–
Brahmanbaria	7	2	2	2	47	12	9	9	17	–	–	–	–
Total	305	146	129	110	7766	2470	1233	854	1565	774	435	246	189

Each district consists of several number of thanas.

community who are subject to the same contamination are not. Early symptoms of arsenic poisoning can range from the development of dark spots on the skin to a hardening of the skin into nodules—often on the palms and soles. The World Health Organization (1996) suggested that these symptoms could take 5–10 years of constant exposure to arsenic to develop (DCH, 1997). Over time, these symptoms can become more pronounced and in some cases, internal organs including the liver, kidneys and lungs can be affected. In the most severe case, cancer can develop in the skin and internal organs, and limbs can be affected by gangrene. While evidence exists that links arsenic to cancer, it is difficult to say how much exposure and for what period of time, will result in this disease.

The results of the project 'Regional Arsenic Survey' broadly agree with earlier survey data but provide better spatial resolution and probably more reliable results at low concentrations. The median arsenic concentration was 0.0108 mg L^{-1}, just above the WHO recommended drinking water limit. The results of the 2022 samples collected in depend shallow tube wells and analyzed in the UK (BGS, 2000) are summarized below:

51% of the samples were above 0.010 mg L^{-1} (the WHO Guideline Value);
35% were above 0.050 mg L^{-1} (the Bangladesh Drinking Water Standard);
25% were above 0.10 mg L^{-1};
8.4% were above 0.30 mg L^{-1};
0.1% were above 1.0 mg L^{-1}.

About 20% of samples have arsenic concentrations of less than 0.003 mg L^{-1} and may be considered essentially 'arsenic-free'. The minimum concentration was below the lowest detection limit of all the methods used (0.0005 mg L^{-1}). The maximum concentration found was 1.67 mg L^{-1}. Therefore, the range of arsenic concentration spans more than three orders of magnitude. Some (14%) of the samples were taken from wells deeper than 200 m. Only about 1% of the samples from these deep wells were contaminated above the Bangladesh standard of 0.05 mg L^{-1}, compared with 41% of contaminated wells in the shallower aquifers. Most of the shallow wells are between 10 and 70 m deep with the water table usually in the range 5–10 m below ground surface (BGS, 2000).

7. Variability of As concentration within area to area in Bangladesh (BGS, 2000)

There are three highly As contaminated districts (Nawabganj, Faridpur and Lakshmipur) were studied in details in the Regional Survey. Approximately 50 wells per thana were sampled (about 1 per 7 km^2) to determine the structure and continuity of the aquifers. A wide range of chemical parameters was measured including dissolved oxygen, redox status and As speciation. Groundwater and monitoring data were also compiled. In Nawabganj, As concentrations exceeded 2 mg L^{-1}. A large proportion of the wells in and around the Nawabganj town had high As concentrations (>0.1 mg L^{-1}). In Nawabganj, 25% of the samples had As concentrations greater than 0.05 mg L^{-1}. As was more uniformly distributed in Faridpur and Lakshmipur, 40 and 55%, respectively, of wells were contaminated. Groundwater from depths of more than 100 m in all the thanas typically had low As concentrations. Water from very shallow hand-dug wells also had low As concentrations.

Arsenic speciation showed that the median percentage of As(III) was close to 50% but there was a wide range of As(III) to As(V) ratios and little relationship with other measured parameters, which is confirms earlier experience in Bangladesh and West Bengal. The more detailed chemical data confirm that the waters are anoxic with high dissolved ammonium concentrations in Faridpur and Lakshmipur (but not Nawabganj), and low nitrate concentrations everywhere except where surface pollution was suspected. In addition, carbon isotope studies support previous deductions that microorganisms play an important role in oxidizing organic matter and maintaining reducing conditions (BGS, 2000).

8. Arsenic poisoning episodes in Bangladesh

Arsenic poisoning episodes have been reported all over the world. Depending on the country exposure to arsenic has come from natural sources, from industrial sources or from food and beverages (Table 7). However, the situation in Bangladesh is especially alarming given the widespread cases of As poisoning reported. In Bangladesh, several studies (Chowdhury et al., 1999; Biswas et al., 1998; Nickson et al., 1998, 2000; Dhar et al., 1997; Khan and Ahmad, 1997; Uddin, 1998; Ullah, 1998; Jakaria, 2000; van Geen et al., 2003) reported that about 25 million people of 2000 villages in 178 arsenic-affected blocks of Bangladesh are at risk of As poisoning and 3695 (20.6%) out of 17,896 people examined are suffering from arsenicosis. To combat the situation, Bangladesh needs a proper utilization of its vast surface and rainwater resources and proper watershed management. Chowdhury et al. (1999) reported that of the 41 out of 64 districts in Bangladesh where As in groundwater was >50 $\mu g\ L^{-1}$, 22 districts had arsenicosis patients and 21 districts had people with arsenical skin manifestations. They surveyed only 98 villages in these districts and found As patients in 95 villages. From these 95 villages, they surveyed at random 6973 people and 2309 people (33.1%) were found with arsenical skin lesions. The detailed information is shown in Table 8.

8.1. Analysis of hair, nail, skin-scale and urine for As from villagers in affected districts

Long time intake of inorganic As is known to induce a build up in the ectodermic tissues like hair and nails (Tables

Table 7
As episodes around the world summarized (mg kg^{-1})

Country	Natural groundwater As contamination	As contamination from industrial sources	As contamination in food and beverages
Taiwan	0.01–1.82		
Chile	0.8		
West Bengal	0.05–0.545		
Mexico	0.5–3.7		
Argentina	0.1		
USA (Utah)	0.18–0.21		
USA (Oregeon)	0.05–1.7		
USA (California)	0.05–1.4		
Canada (Ontario)	0.10–0.41		
Canada (Nova Scotia)	>3.00		
Hungary	0.06–4.00		
New Zealand	8.5		
Alaska	0.05–0.07		
China	2.20–20.00		
Navada	0.10		
Japan	0.01–0.293		
Vietnam	0.01–3.05		
Thailand		0.05–5.00	
Philippines		0.1	
Japan		0.025–4.00	
India (Calcutta Mitra)		0.05–58.00	
India (Madhya Pradesh)		0.88	
Czechoslovakia		900–1500	
Canada (Ontario)		20.00–82.00	
Greece		1480–3800	
Ghana		<0.002–0.175	
USA		0.482	
Mexico		4.00–6.00	
Scotland		0.52–64.00	
Bulgaria		0.75–1.50	
Japan (soyasauce)			5.6–71.60 (mg L^{-1})
Japan (milk)			13.5–21
England (milk)			1.14–9.12
China (Guizhou)			100–9600
China (Yunan)			300–1100

9 and 10). It could be assumed that higher values of As in hair samples were due to long time accumulation of As through contaminated drinking water sources (Das et al., 2003).

9. Discussion

9.1. Future trends

According to laboratory data reported by Rahman et al. (2002) millions of people in Bangladesh and West Bengal India are still being exposed to high levels of As in their drinking water, despite a million dollars of screening effort to distinguish safe from unsafe wells. Erickson (2003) suggested that field kits used to measure As in the region's 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 1997 to test all handle pumped tube wells using colorimetric field kits. To date, more than a million wells have been tested using the kits. Those with As levels >50 mg L^{-1} were painted red to indicate that the water is unsafe for drinking, and those with levels <50 mg L^{-1} were painted green to indicate that the water is safe. Millions of dollars have been spent testing the wells and millions more are slated for future screening efforts. However, on the basis of laboratory data reported by Rahman et al. (2002), the accuracy of these data is now questioned. Using a more accurate and precise technique called flow injection hydride generation atomic absorption spectroscopy (Fl-HG-AAS). Rahman et al. (2002) analyzed 2866 water samples from wells that were painted either red or green by field workers. For samples with As levels <50 mg L^{-1}, they found that 45% were mislabeled. For samples with higher As levels, however, the percentage of wells that were mislabeled was significantly lower (Hussam et al., 1999; Erickson, 2003). According to Erickson (2003), the kits rarely gave wrong indications at the concentrations. UNICEF is still using field

Table 8
Results of a detail study of 21 districts of Bangladesh where As patients were identified (Chowdhury et al., 1999)

Districts	Area (km^2)	Total no. of thana	Population (million)	Total no. of thanas surveyed	Total no. of thanas where patients identified	Total no. of villages surveyed	Total villages where patient identified	Total population surveyed	Proportions of As patients identified (%)
Nawabganj	1702	5	123200	1	1	4	4	236	61
Kushtia	1621	6	1563000	3	3	8	8	404	44
Rajshahi	2407	13	1988000	2	2	2	2	76	61
Meherpur	716	2	511000	1	1	3	3	210	38
Pabna	2371	9	2016000	4	4	6	6	572	29
Chuadanga	1158	4	844000	1	1	2	2	204	51
Jessore	2567	8	219200	3	3	6	6	1445	29
Khulna	4395	14	2130000	2	2	5	5	304	34
Gopalganj	1490	5	1097000	2	2	3	3	31	71
Madaripur	1145	4	1106000	1	1	3	3	79	23
Satkhira	3858	7	1660000	1	1	2	1	138	39
Bagerhat	3959	9	1489000	2	2	9	9	438	45
Magura	1049	4	752000	3	3	3	3	100	38
Faridpur	2073	8	1558000	1	1	6	6	288	33
Noakhali	3601	6	2347000	3	3	9	9	425	24
Lakshmipur	1456	4	1391000	2	2	14	13	1540	27
Narsinghdi	1141	6	1710000	1	1	1	1	33	36
Rajbari	1119	4	865000	1	1	2	2	16	50
Narayanganj	759	5	1819000	1	1	4	3	209	24
Chandpur	1704	7	2149000	3	3	3	3	150	28
Comilla	3085	12	4263000	3	3	3	3	75	21
Total	43376	142	32709200	41	41	98	95	6973	33[a]

[a] Mean.

kits to test well in Bangladesh for As but it is continually changing products. UNICEF will begin using the recently designated Arsenator. In addition, UNICEF is keeping an eye on a kit being developed at Mahidol University in Thailand, which also uses a handheld photometer, and another kit being developed at Columbia University based on the molybdenum blue method which does not produce arsine gas (Hussam et al., 1999; Christen, 2001). Christen (2001) and Erickson (2003) believe the As problem is getting worse now because many wells that were reported safe are now showing high levels of As but according to others no evidence supports this kind of trend. Ideally the wells should be tested more than once (Erickson, 2003). It is unlikely that repeated testing will be carried out by the government or donor agencies. Well owners are encouraged to retest their wells, preferably twice a year and not every year at the same time. Private testing agencies are currently not available in Bangladesh but UNICEF is working to develop new approaches to make private testing available in the near future (Erickson, 2003).

9.2. Influence of pumping and irrigation

There is no long-term water quality monitoring data to definitively establish how As concentrations change over time. Very few data that exist, extending over no more than two years, show that some wells have increased in concentration. However, they cannot yet be taken as proof of general or systematic changes. The Regional Survey shows a correlation between the year of construction and the proportion of contaminated wells above the Bangladesh standard. In average, older wells are more likely to be contaminated than recently constructed ones. Only long-term monitoring will determine whether this actually corresponds to increasing concentrations at individual wells.

Table 9
As concentration ($\mu g\ kg^{-1}$) in hair, nail and skin-scales of five As patients where As in tube well water >50 $\mu g\ kg^{-1}$ (Eisler, 1994)

Districts	Villages	Hair	Nail	Skin-scale
Salkhira	Krishnakadi	6990	14000	11250
Bagerhat	Bailtali	2050	3150	2140
Lakshmipur	Shibpur	19510	40100	9260
Comilla	Orain	3170	4290	–
Noakhali	Lakuriakandi	5580	10000	5080

Table 10
As in urine, hair and nails of control population of Chittagong in Bangladesh where As in tube well water <50 $\mu g\ kg^{-1}$ (Eisler, 1994)

Parameters	Mean	Range	Standard deviation	No. of samples
Urine ($\mu g\ L^{-1}$)	31	6–94	20	62
Hair ($\mu g\ kg^{-1}$)	410	120–850	180	62
Nail ($\mu g\ kg^{-1}$)	830	90–1580	680	62

A key policy issue for the water sector is the possible influence of pumping. For domestic use and irrigation there is extensive withdrawal of groundwater. Although the number of hand pumps is much greater than the number of irrigation wells, by volume they only account for about 10% of groundwater extraction. The critical question is whether or not pumping of groundwater for irrigation is either creating or exacerbating the problem of arsenic in drinking water. The influence of pumping for irrigation could be expressed by either increased flow of groundwater through the aquifers or by the lowering of the water table. To test these ideas, we looked for a spatial correlation between the areas of most intense arsenic contamination and the distribution of groundwater extraction as well as also the deepest groundwater levels. No correlation with either heavy extraction or deep groundwater levels could be found. In fact, the areas of greatest contamination never coincide with either the deepest water levels or the most intensive extraction.

Possible changes over time were also investigated through the use of numerical groundwater flow and transport models. Modeling the impact of a typical 0.5 cusec irrigation shallow tube well (STW) with a 6 ha command area indicates that even under conditions of relatively low arsenic sorption, movement of the arsenic might be of the order of 50 m in 15 years. Therefore, while irrigation wells will enhance the movement and dispersion of arsenic, this effect is likely to occur over the timescale of decades.

Although there is evidence that enhanced fluctuation of the water table is not responsible for mobilization of arsenic, this is not to say that irrigation will have no influence on the arsenic problem. In particular, the widespread cultivation of Boro rice (*O. sativa* L.), a high yielding variety, provides just the conditions that would minimize air entry to the underlying aquifer and would therefore make any ongoing reduction and arsenic release more effective. This process would probably take a long time to have an effect, and cannot account for the large-scale problem that currently exists. It nevertheless needs further investigation.

The effect of phosphate fertilizers also needs investigating. Phosphate concentrations in groundwater are abnormally high—frequently more than 0.5 mg L^{-1} (as phosphate—P) and this could make the arsenic more soluble by competing with arsenic for sorption sites on the iron oxides. However, most of the phosphate is suspected to be derived from natural geological sources.

9.3. Effects of floods

Floods are a normal occurrence in Bangladesh. Although the severe flooding in the 1998 and 2003 monsoon was exceptional, it is unlikely that floods have any long-term effect on the arsenic problem. There may be some increased flow in the uppermost part of the shallow aquifer but this will, if anything, tend to flush out the arsenic that is found there (BGS, 2000).

9.4. Future needs

The review findings indicate the distribution of As is far from uniform. Overall, the literature review indicates that, in Bangladesh, most of the samples from irrigation and domestic groundwater were found to have As concentrations higher than international and local permissible standards set by WHO (1993). The As concentration was reported to be higher in the shallow than the deeper aquifers. The impact of using contaminated irrigation water from shallow tube wells needs investigating from the point of view of possible entry of arsenic into the human food chain, the animal food chain and any effect on soil quality, particularly its microbiological functioning. Growing rice with As contaminated irrigation water was further associated with higher As concentration in Bangladeshi soils and plants (data based on 4% area of the country) than the permissible limits or normal range reported. This situation poses a series health hazard to human and livestock.

The Bangladeshi government, WHO, BGS and other international organizations have not yet considered the possible health effect of As contaminated irrigation water on the livestock. It is the time for identifying such a critical problem; hence, detailed study related to As problem in irrigated soils, water and plant should be conducted without delay. In addition, cheap and efficient uses of methods for the removal of As from drinking water need to be adopted. The interaction of the sediments with groundwater is a key aspect of the As problem that is not well understood. This needs to be determined in order to predict the rate of movement of arsenic in the aquifer and how it might change with time. It is extremely important to carry out appropriately designed program on As contamination and hazards monitoring aimed at minimizing its exposures to human and livestock. Many researchers also suggested that an on-farm field study of crops grown on As-contaminated soil is urgently needed and a strong awareness is to be created through the government media, as well as non-governmental social welfare groups to educate the public about the hazards of all kinds of contaminants, particularly As contamination of food, water and environment.

The most immediate short-term requirement is the provision of safe drinking water in arsenic-affected areas. This could be accomplished either by treatment, which is unlikely to be a satisfactory long-term solution, or by development of alternative safe water sources as a matter of urgency, which can form part of the long-term investment in improved water supplies. Consumers are reluctant to pay for As removal or for less convenient alternative supplies than their own hand pumps, while GOB can ill afford the cost of providing treatment or alternative resources. The strategy must therefore be move towards systems, which will attract consumer investment because they represent an improvement in convenience of access, and are sustainable. GOB funding for both capital and recurrent costs can then be reduced. The systems must be designed around consumer demand and actively involve women in their formulation and operation.

Substantial further investment is also required for water supplies in towns, some of which have existing systems but the coverage is often limited. The conventional systems based on large DTWs will be appropriate for many areas, provided the wells are deep enough to provide safe water. Funds for expansion, sustainability and achieving higher coverage are the main issues. Government policies advocate involvement of the private sector, which needs to be given greater encouragement to respond directly to consumer needs, rather than government agencies acting as intermediaries who may opt to involve the private sector when it suits them.

The general observations made by the alternative water supply groups recognized that alternative technologies are area-dependent and cannot be prioritized for the whole country. The country is broadly divided in to shallow water table area, low water table area, coastal saline area, stony area, Madhupur and Barind Tract area, and Chittagong Hill Tract area requiring technological variations. No single option can serve the purpose of the people having different social and economic conditions. Choice of the communities should be given priority in the selection of technology options and there exists knowledge gap in some areas that implies decision-making regarding selection of alternative technologies for As-affected areas. Therefore, there is a need for coordinated research with both interdisciplinary and intersectional was highly emphasized.

10. Conclusion

Based on the review, three main questions remain unanswered regarding the arsenic problem: (1) is the problem becoming worse and if so, will it continue to worsen? Or, is it that more consistent and more accurate testing continues to record an increased incidence of arsenic? (2) Has the increased use of groundwater for irrigation purposes caused As to be mobilized and enter the groundwater? (3) How acute is the risk that As in irrigation water will enter the food chain?

At this time, there are no firm answers to these questions. However, it is evident that more testing increases the known number of As-infected wells; particularly since a new, low-cost field test kit has been developed in Bangladesh. Few kits can detect As concentrations below 20 $\mu g\ L^{-1}$. Opinion was divided as to whether increased extraction of water for irrigation has caused an increase in the concentration of As in groundwater. There is no evidence to prove any linkage apart from the fact that the recorded increase in the incidence of As in groundwater has coincided with the general increase in the use of groundwater for irrigation.

The review also reveals that small amounts of As accumulate in rice grains, but is highly concentrated in the roots. Studies have also shown that some green leafy vegetables accumulate As. However, research is urgently needed to improve understanding of the mechanisms involved and the associated risks, particularly in the context of irrigated agriculture.

It is also observed that a number of gaps in the scientific knowledge exist; only a few of them are mentioned here. Firstly, ingestion of As through other routes such as contaminated food has not been studied adequately. A vast majority of the contaminated groundwater is utilized for irrigation purposes. The potential uptake of As into plants and foods from the irrigation water, retention in soils and leaching back to shallower aquifers have not been investigated. Secondly, soil retention of As can lead to As-laden dust particles—these have not been explicitly studied as an ingestion route. Some of these issues highlight the need for scientific studies that would describe the fate of As in the natural environment and identify all potential routes of exposure.

Finally, I would like to raise some questions to conclude this literature review. First, is it worthwhile at this time to conduct a collaborative program on As research with all As scientist and funding authorities involved in Bangladesh. That is, do the participants of As research in Bangladesh think that it would be valuable to conduct research to meet Bangladeshi people needs in respect to As issues, as a part of wide ‘‘program’’ that is tailored to directly meet Bangladeshi peoples need as opposed to continuing with individually sponsored work. If the answer is positive then the second question becomes: is there a desire to see a steering committee go forward following up on findings of this manuscript to determine the levels of financial commitment that could be obtained from potential funding partners, and proceed to develop the Bangladesh by providing As-free food, water and environment?

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