Arsenic Contamination of Groundwater in Bangladesh

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The International Irrigation Management Institute, one of sixteen centers supported by the Consultative Group on International Agricultural Research (CGIAR), was incorporatcd by an Act of Parliament in Sri Lanka. The Act is currently under amendment to read as International Water Management Institute (IWMI).

Contents

Background and Objective of the Paper

Hailed as a public-health success story in the 1980s, Bangladesh is now associated with the world's biggest environmental health crisis of the century—chronic poisoning of exposed populations by arsenic concentrations in groundwater well above the WHO guideline of 0.01 mg/l.

Over the last two decades in Bangladesh, untreated tube well water (which is usually bacteriologically 'safe') was heavily promoted and developed as a safe and environmentally acceptable alternative to untreated surface waters, which are generally unsafe from a microbiological standpoint. Such a policy, promoted primarily by the UNICEF and other agencies dealing in water supply, was launched to combat the high mortality rates resulting from diarrheal diseases through the consumption of unsafe water by the vast majority of people in developing countries and in particular children and infants. The program was a success till the recent discovery that the groundwater in certain parts of Bangladesh and West Bengal (India) was heavily contaminated with arsenic and that the population drinking this water was showing symptoms of arsenic poisoning.

In researching the explanations behind the arsenic contamination of groundwater, one of the first theories put forward was that overexploitation of groundwater, in particular for irrigation purposes, was linked to the high incidence of arsenic contamination of the groundwater.

To determine the validity of this theory, which could have far reaching consequences for the agriculture and irrigation sector, the International Water Management Institute (IWMI) decided to investigate the issue through a review of current literature on the subject and through discussions with key informants involved in researching solutions to the problem. **A** further reason for this exercise was to provide IWMI with sufficient facts to make informed decisions regarding the future role that IWMI might be called upon to play in the search for solutions to the arsenic contamination problem in Bangladesh, particularly in relation to arsenic in the agriculture/irrigation cycle.

A large body of documentation is already available on the subject, which has become an international issue. Many initiatives are underway to the point that it seems like 'everybody wants a piece of the action' and there is a feeling amongst some involved persons that this is leading to duplication of actions with very inefficient use of available resources.

The present document is the result of IWMI's investigation of the subject, and a good portion of the document reflects the findings of a very comprehensive report (BGS and MML 1999) prepared, in January 1999, for the Government of Bangladesh by the British Geological Survey in collaboration with Mott MacDonald Ltd., a British consultancy firm, and financed by the Department for International Development, UK. The investigation and the findings were supplemented by information received during discussions conducted by the author during a field mission in Bangladesh in September 1999.

Introduction

Elevated toxic concentrations of arsenic have been reported in air and water samples from around the world, most notably from China, Taiwan, Japan, Mexico, Chile, Argentina, USA, Canada, new Zealand, Europe (Hungary, UK), Ghana, Thailand, India and Bangladesh. At least 75 percent of the global atmospheric arsenic has been reported as anthropogenic. Elevated arsenic concentrations in water can result from both anthropogenic activities and natural processes. The primary mineral sources of mobilized arsenic are pyrite (FeS_2) and arsenopyrite ($FeAsS$). Pyrite is a ubiquitous mineral, occurring in most major rock types. The close association of arsenic with pyrite reflects the geochemical affinity of arsenic with sulphide mineral formation in sedimentary and hydrothermal environments (Nordstrom 1998).

Arsenic Contamination of Groundwater in Bangladesh—Scale of the Problem

The problem was first identified in Bangladesh in 1993 in the far west of the country (adjacent to West Bengal in India), after reports of contamination in India in 1988. Since 1995, detailed and extensive surveys have been carried out, funded and executed by various agencies to assess the situation. These included two nationwide surveys as well, which gave the true extent of the problem. The Asian Arsenic Network first involved itself in the problem in Bangladesh in 1996 following the publicity given to the issue in West Bengal. But it was in 1997 that public awareness was raised to a high degree and the World Bank arranged a fact-finding mission to assess the situation and initiate a mitigation program. This was the forerunner to the project entitled Groundwater Studies for Arsenic Contamination in Bangladesh financed by the DFID, carried out by the British Geological Survey in collaboration with Mott MacDonald Ltd., who prepared the first detailed and comprehensive report on the situation (BGS and MML 1999). Through a systematic survey undertaken in 41 of the **64** districts of Bangladesh, **2,022** well water samples were analyzed for arsenic (one sample per 37 square kilometers). The results of this survey are presented in figures 1a and 1b. In summary, of the samples:

- 51 percent > 0.01 mg/l (WHO Guideline value)
- 35 percent > 0.05 mg/l (Bangladesh drinking water standard)
- **25** percent > 0.10 mg/l
- 8.4 percent > 0.30 mg/l
- 0.1 percent > 1.00 mg/l

The problem of arsenic in groundwater is serious in much of southern and eastern Bangladesh (though its first manifestation in Bangladesh was in the western states close to the West Bengal border) and, in terms of population exposed, it is the most serious groundwater arsenic problem in the world. Other countries that have manifested this problem of contamination from natural (geological) sources are parts of the United States, Argentina, Chile, Mexico, West Bengal, and Inner Mongolia. The recent manifestation of the problem in Bangladesh may be because groundwater has been used extensively only in the last ***20-30***

Figure 1a. Percentage of groundwater samples from the shallow aquifer (less than 150 m deep) exceeding the Bangladesh standard for arsenic in drinking water (0.05 mg/l).

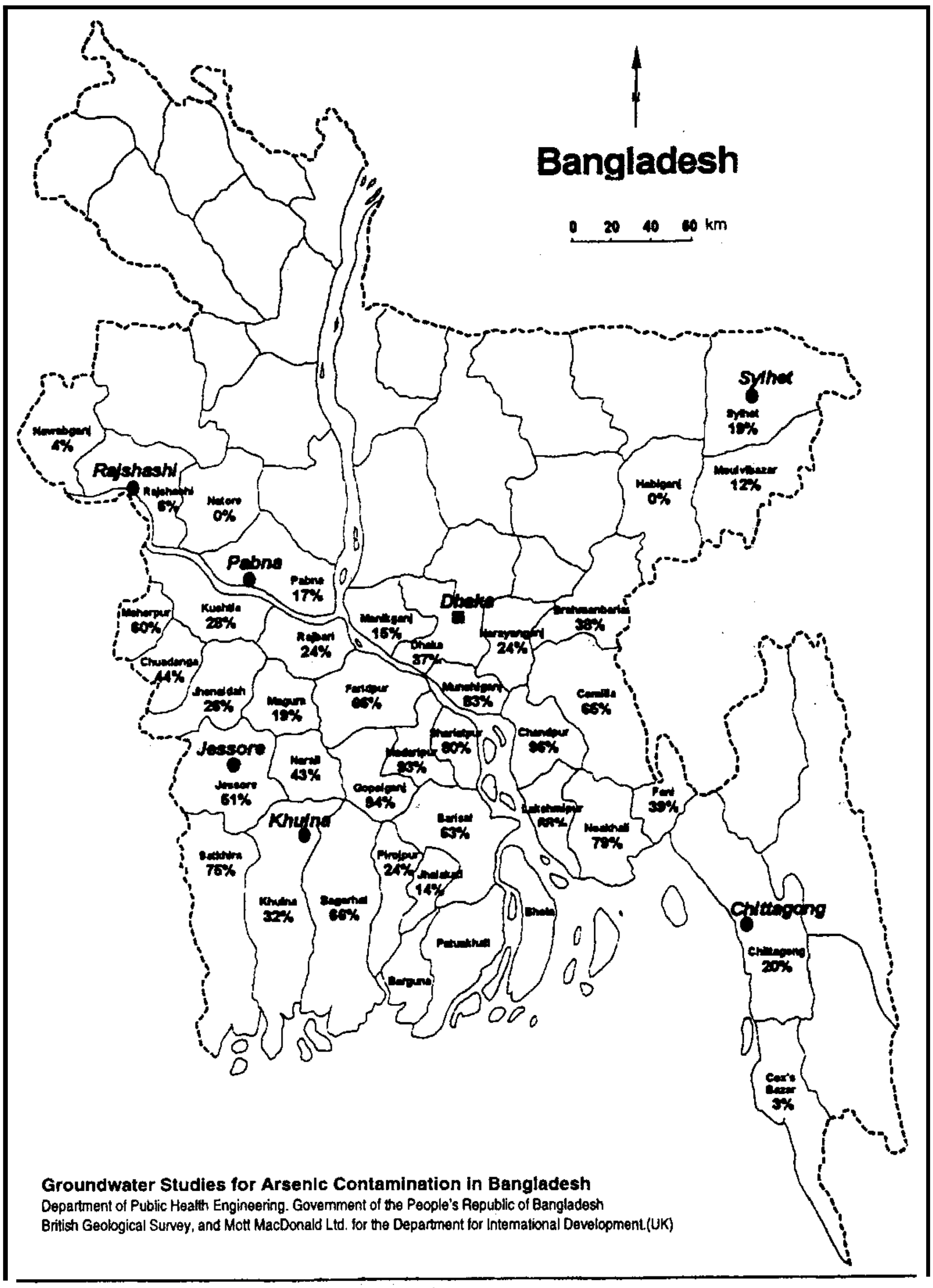
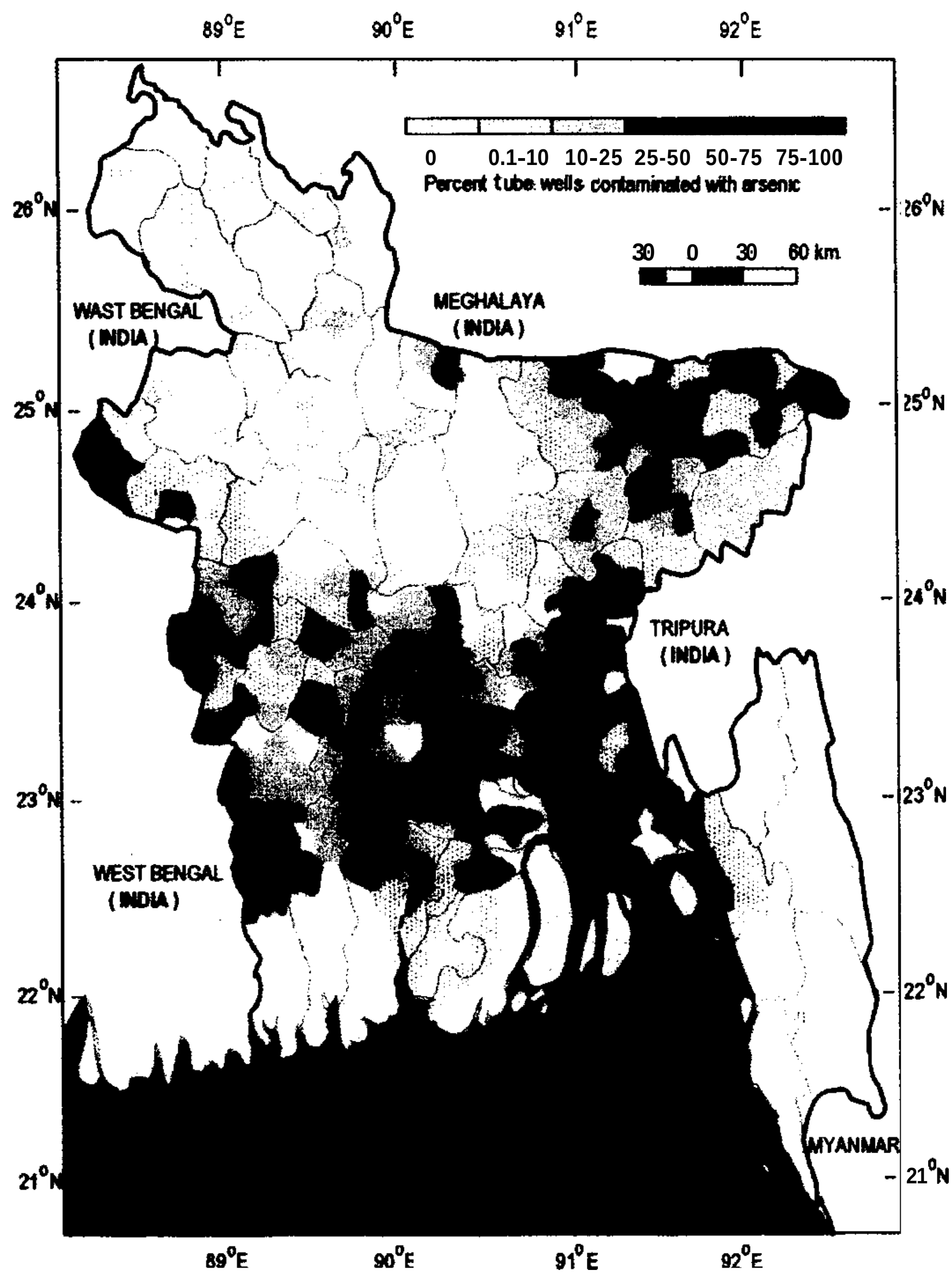


Figure lb. Arsenic contamination of groundwater in Bangladesh.



years (the arsenic has probably been present in the groundwater for thousands of years). Extensive exploitation for drinking purposes (4 million tube wells, and at least an estimated 95% or more of the population use groundwater for drinking) was encouraged only in the last two decades, by the government and other agencies as a strategy to combat the high infant mortality from diarrheal disease, a strategy that was indeed found to be successful. Arsenic poisoning symptoms take **5** to 15 years to manifest themselves.

It is interesting to note that in early 1994, the National Minor Irrigation Development Project (NMIDP 1955) commissioned a baseline Water Quality Survey on groundwater and some surface water, to detect pesticide and fertilizer residues, in critical zones where groundwater irrigation and cropping intensities were high and where there was intensive application of pesticides and fertilizers. The question of arsenic contamination of groundwater was not obviously a national issue at this time and this parameter was not measured. Later, in early 1997, after arsenic contamination had become a national issue, the North-East Minor Irrigation Project (NEMIP) of Bangladesh commissioned a randomized survey of arsenic in irrigation wells (1,200 samples) in six districts of North East Bangladesh (figure **2** shows the combined test results run by two different laboratories for the NEMIP).

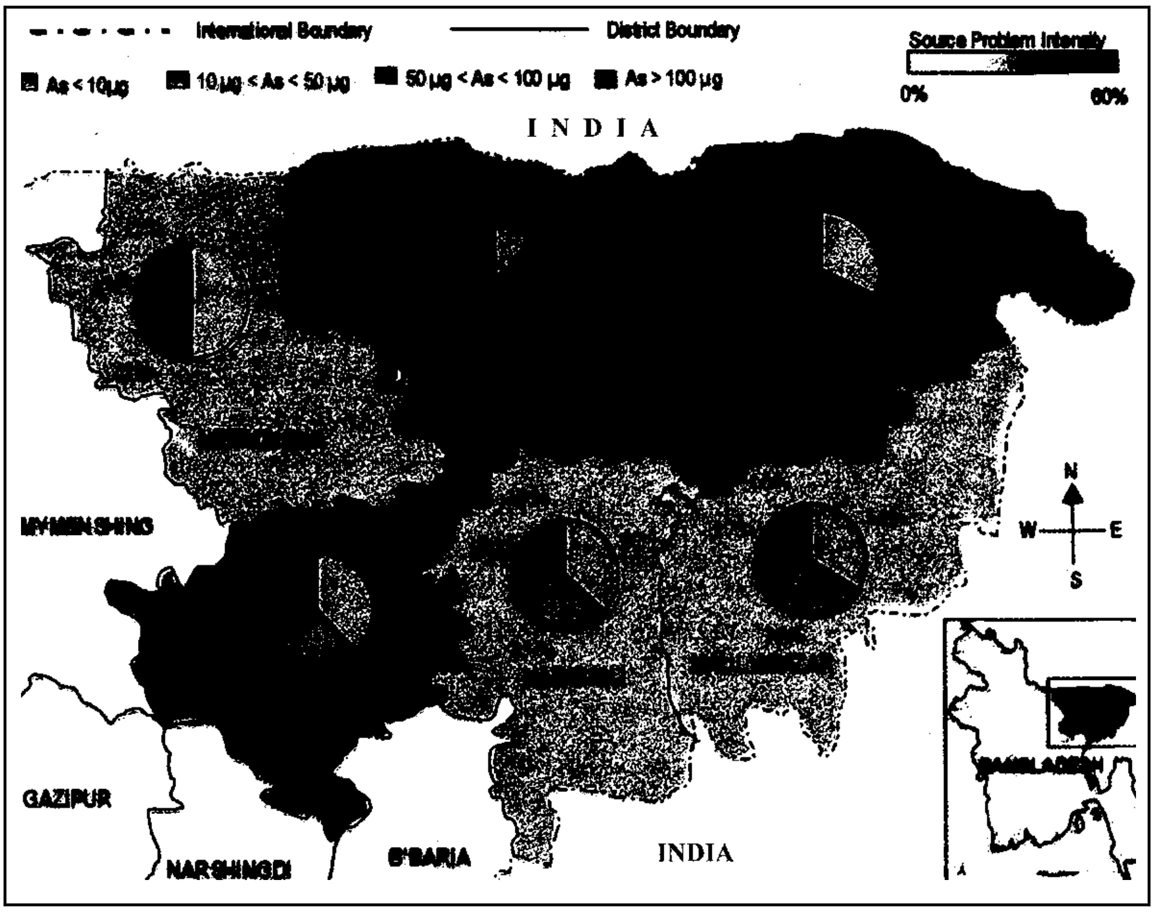
Patient surveys were carried out as well. The first international conference on the subject of arsenic contamination in Bangladesh was held in 1998 (International conference on arsenic poisoning of groundwater in Bangladesh Causes, effects and remedies; Dhaka; 105 papers were presented) and was the first major opportunity for sharing knowledge and information on the subject. Since then a number of conferences and seminars have addressed different aspects of the problem.

Arsenic Standards: Testing Procedures and Data Storage

The present standard for arsenic in Bangladesh is 0.05 mg/l. The country has retained this original value utilized by WHO when drinking water standards for this element were set. In 1993, WHO made it more stringent to 0.01 mg/l based on new information. Neither India nor Bangladesh has changed its standards.

Though arsenic testing facilities were strengthened in some of the laboratories in Bangladesh they still remain inadequate. The two methods generally available at laboratories in Bangladesh are hydride generation atomic absorption spectrometry (HG-AAS) and **silver** dithiodicarbamate **(SDDC)** spectrophotomehy. The scale of arsenic contamination and the need for providing feedback to water users have led to the development of field-test kits by various agencies. **All** are based on the mercuric bromide stain method. It was concluded in the course of various studies that field-test kits provide a reliable way to identify contaminated water above 0.2 mg/l. The reliability is much less for values below this and should be used with caution. Surveys using field test kits also demonstrated the potential for community involvement in testing programs. Data on arsenic are available in a computerized database, geocoded and where possible geo-referenced. The data have been incorporated in a **GIS** for analysis and production of hazard maps. ***A*** CD-ROM of all data **is** available as well.

Figure 2. Intensity of arsenic pollution in the northeastern zone of Bangladesh.



Source: Ahmed, Feroze 1999.

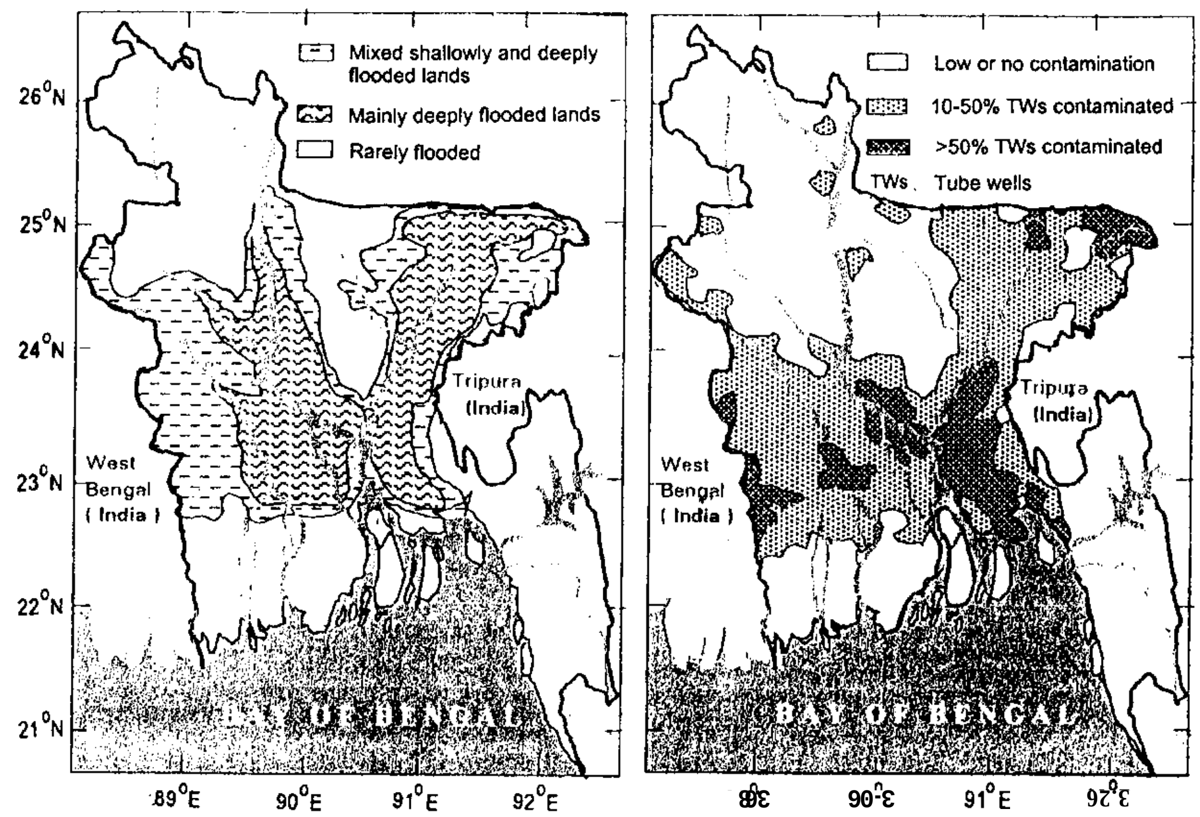
Origin and Distribution of Arsenic

Arsenic (As) contamination in Bangladesh is of geological origin, from alluvial and deltaic sediments in areas where the water table is generally high (7 m). A high water table is characteristic in most parts of Bangladesh, except in areas that are drier and in areas where intensive groundwater irrigation has increased the annual decline of the water table. However, the high rainfall ensures that the aquifer is fully recharged every year. In Bangladesh, the shallow aquifer seems to be the one that is contaminated by arsenic. No arsenic contamination has been found to date either in the shallow hand-dug wells (< 10 m in depth) or in the groundwater drawn from depths greater than 150–200 m, even in areas otherwise manifesting high arsenic contamination. No arsenic contamination has been found in Dhaka tube wells either.

The University College of London, in collaboration with the Dhaka University and others, conclusively demonstrated the geological control over the distribution of arsenic in groundwater. This study also led to the main alternative explanation to the pyrite oxidation hypothesis (see section on Mobilization and Transport of Arsenic in Groundwater) for the origin of arsenic, which was the prevalent thinking till then. Studies also show that there are both regional and local patterns to the distribution of arsenic in groundwater. Regionally, the most contaminated areas are to the south and east of Dhaka. There is a strong correlation with surface geology and geomorphology and hydrogeological parameters. The worst affected aquifers are the alluvial deposits of the recent floodplains. Of the extensive geological units, the most contaminated groundwater is found beneath the Chandina Alluvium, Deltaic Silt and Deltaic Sand. Geomorphologically, the most contaminated areas are in the Meghna River Floodplain and the Old Estuarine Floodplain. Typically, the content of arsenic in alluvial sediments is in the range **of 2–10** mg/kg and it appears likely that a good portion of this is in the adsorbed form. **An** explanation for the adsorbed form of the element is that the original sources of arsenic, which were in the form of both sulphide and oxide minerals, were oxidized releasing arsenic in the soluble form as As (V), which was subsequently adsorbed by the secondary iron oxides formed. The greatest arsenic concentrations are mainly found in the line-grained sediments, especially the gray clays. The older sediments are not significantly rich in arsenic. There are also important differences related to the floodplains.

The nonuniform distribution of arsenic in groundwater is described using the term "hot spots" (one tube well **may** have very high concentrations of arsenic whilst a neighboring tube well may be free of arsenic contamination) and some experts (Hansen 1999) have tried to explain this phenomenon by linking it to the nonuniform pattern of sedimentation over geological time zones. The meandering nature of the rivers in Bangladesh and the displacement of the riverbed both horizontally and vertically over time caused a nonuniform deposition of the arsenic-laden sediments washed down from the bedrock of the Himalayan region. The pattern of distribution **of** arsenic in groundwater could also be linked, according to another expert (Ahmed 1999) to the flooding patterns exhibited by the rivers draining the floodplain. According to this, most of the areas having over 50 percent of tested contaminated tube wells, fell into the mainly deeply flooded areas (see figure **3),** the rarely flooded lands having no significant arsenic contamination.

Figure 3. Relation between flooding pattern and arsenic contamination.



Source: Ahmed, Feroze 1999.

Mobilization and Transport of Arsenic in Groundwater

A wide range of explanations for the origins of arsenic in groundwater in Bangladesh have been put forward. Of all the natural and anthropogenic theories investigated, only those proposing a geological origin can account for the widespread distribution of arsenic. Of the geological explanation, two hypotheses have gained prominence—the pyrite oxidation theory and the oxyhydroxide reduction theory. Thus far, evidence points to the latter being the most likely explanation. It was the former theory that linked overexploitation of groundwater (for irrigation in particular) with the increased incidence of arsenic contamination.

(Arseno)Pyrite Oxidation

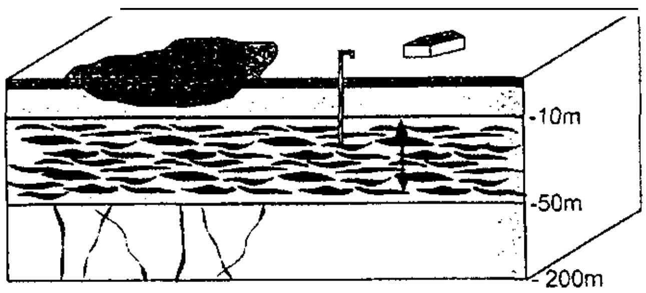
This process accounts for the arsenic pollution of both surface water and groundwater in many mining areas around the world, particularly in the USA. Arsenic is assumed to be present in certain sulphide minerals that are deposited within the aquifer under reducing conditions. When air (oxygen) enters the system as a result of pumping of groundwater or any other human activity, or even in the presence of another oxidizing agent like nitrate, it oxidizes the sulphide mineral following the simplified schema shown in figure 4 and arsenic gets released into the pore water, which then mixes with the shallow groundwater when the water table subsequently rises. Continued pumping eventually draws down the arsenic-rich water into the intake zones of the shallow tube wells. According to this theory, the greater the volume abstracted the greater the drawdown of the water table and the greater the release of arsenic into the groundwater.

Oxyhydroxide Reduction

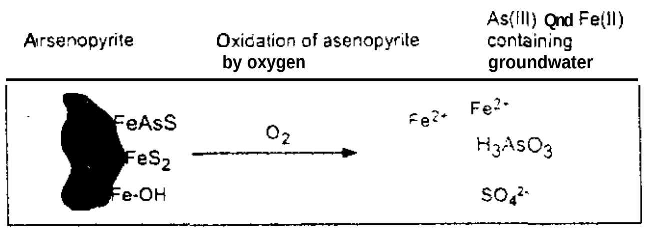
Field evidence in Bangladesh is not consistent with the pyrite oxidation theory. In the alternative explanation it is believed that arsenic is transported and deposited in the adsorbed form on fine-grained iron or manganese oxides (amorphous iron oxyhydroxide, which is the potential arsenic-bearing mineral, retained as the source of arsenic, is well known for its ability to adsorb arsenic under oxidizing conditions during sediment-water interactions and to readily release adsorbed arsenic under reducing conditions). This arsenic-bearing mineral, after burial, slowly breaks down as the pore water of the organic-rich sediments become more reducing over time (i.e., once the dissolved oxygen has been consumed in the decomposition of organic matter present in the sediments and once all other sources of oxygen such as nitrates and sulphates are consumed as well), releasing the arsenic. In support of this theory, various studies have shown that the water is rich in ferrous iron indicating that anaerobic conditions had existed that led to the reduction of the ferric iron. **Also** uniformly low sulphate concentrations were found, which is contrary to the expectations of the pyrite oxidation theory. Mineralogical and sedimentological studies showed insignificant amounts of pyrite in the aquifer sands but the conspicuous presence of ferruginous coatings on sand grains that were rich in adsorbed arsenic, further support this theory. **A** summary of the main evidence relating to mobilization has been extracted from the BGS and MML **1999** report and is shown in table 1.

The highly reducing nature of the groundwater has led to the reduction of some of the arsenic to As (III) resulting in possible increased desorption of arsenic since this form of arsenic is less strongly sorbed by the iron oxides than **As** (V) under the near neutral pH conditions observed. If strongly reducing conditions manifest, then other strongly sorbant ions like phoshate get released as well from iron oxide dissolution, and compete with **As** (V) for the sorption sites, thus tending to increase the concentration of arsenic in the water. Presence of phosphate (from anthropogenic **sources,** e.g., fertilizer **use)** can aggravate the arsenic problem and make arsenic treatment more difficult.

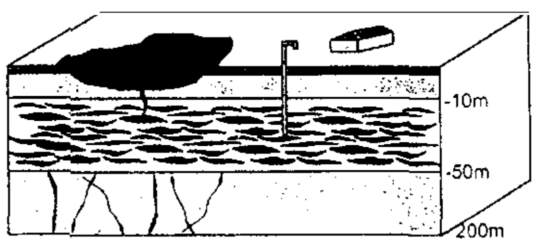
Figure 4. *Hypothesis* ***for*** ***arsenic mobilization*** *in* ***groundwater*** *(The arsenopyrite-hypothesis).*

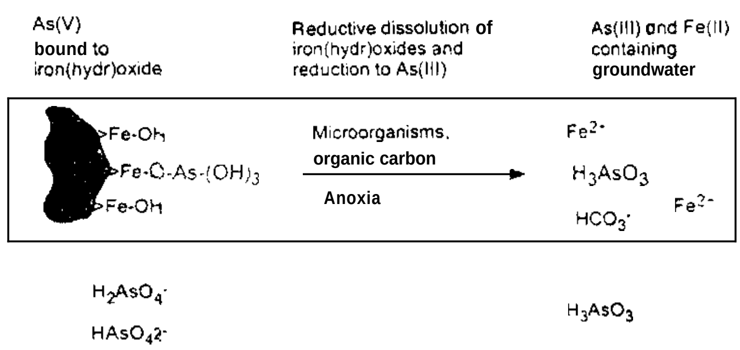


Mobilization of **arsenic by oxygen**



Mobilization of **arsenic by Infiltration of anoxic water**





Source: Swiss Federal Institute for Environmental Science & Technology, EAWAG 1999

Table 1. Summary of evidence relating to the mechanism of arsenic release.

Hydrochemical Parameters	
Dissolved oxygen	High arsenic is found in oxygen-poor groundwater.
Redox conditions	High arsenic occurs predominantly in strongly reducing water.
Sulphate	Very low concentration in general, and no correlation with arsenic.
Bicarbonate	Concentration is generally high, and correlates positively with arsenic.
Iron	Almost all water with a high arsenic concentration contains a high iron concentration but the latter does not necessarily indicate a high arsenic concentration.
Chloride	Generally low all over the country, an apparent positive correlation with arsenic in coastal areas.
Phosphate	Positively correlates with arsenic.
Sedimentology and Mineralogy	
SEM studies	Authigenic framboidal pyrite is being formed in the aquifers and detrital amorphous iron oxyhydroxides get corroded.
Sediment chemistry	A very strong positive correlation between iron and arsenic and leaching tests confirm that arsenic is diagenetically available. Sulphur phases are rare and no arsenic-sulphur correlation exists. Finer fractious contain high concentrations of arsenic.
Optical microscopy	Detrital grains of pyrite are very rare. Conspicuous ferruginous coatings on the **quartz** and feldspar grains in contaminated aquifers.
Field Relations	
Depth distribution	Very shallow aquifers (<10 m) generally contain low arsenic concentrations in most cases, whilst very high arsenic concentrations (>0.5 mg/l) are almost entirely restricted to the upper 50 m, and below 100 m few wells exceed 0.1 mg/l. At specific localities (e.g., Faridpur, Tungipara and Manikganj) concentration has been observed to increase with depths down to 70 m. Deep aquifers (>200 m) in the coastal area contain low arsenic concentrations, generally below the WHO Guideline, but may locally exceed the Bangladesh Standard.
Water level	There is no relationship between arsenic occurrence and depth of water level.
Abstraction	No relationship between amount of pumping and arsenic concentration.
Geographical distribution	The fact that the highest arsenic concentrations are found in the lower part of the delta suggests a secondary enrichment process.
Geological distribution	Arsenic occurs in the Recent Alluvial aquifers and not in the Plio-Pleistocene aquifers.

Source: **BGS** and MML 1999.

Future Trends of Arsenic in Groundwater

BGS and MML (1999) studied the geographical distribution of cumulative groundwater pumping to construct temporal trends, as no systematic monitoring data existed. The temporal trend of arsenic is assumed to be directly related to the circulation of water through aquifers. It was concluded that there is no correlation of arsenic occurrence with present gross abstractions of groundwater, and the highest occurrences of arsenic are not in the areas of most intensive abstraction. The basic distribution of arsenic in groundwater existed before the onset of pumping, and any trends resulting from the impact of pumping will be secondary, and will require careful measurement and statistical validation. Groundwater flow and contaminant transport modeling studies were conducted to predict the possible movement of arsenic away from hot spots. This provided the answers to a number of questions that were posed, in spite **of** the fact that such modeling studies give only an approximate insight into arsenic movement. The answers to some key questions are given in table **2.**

Results from direct monitoring of a few wells and from indirect observation do indicate that arsenic concentrations may be increasing with time but evidence is inconclusive. The regional survey established a correlation between age of wells and the percentage of wells contaminated by arsenic over a period of more than 20 years, but there clearly is a need to continue monitoring studies for at least a decade **or** longer.

The risk of contamination of the uncontaminated deeper aquifer through transfers of arsenic from the shallower aquifer has been the concern of a number of experts as well, when discussing the possibility of extracting groundwater from the deeper aquifer for potable use. Whilst there is reason to believe that poor-quality lining of the tube well would enhance the risk of such transfers, according to Ahmed (1999), in normal circumstances the risk is negligible. In most of the aquifers in question, an impermeable layer separated the ‘shallow’ aquifer from the ‘deep’ one. Furthermore, there **is** an underground horizontal flow of water in the deeper aquifers, which will therefore minimize or even eliminate vertical transfers between water phases. The source of replenishment of the deeper aquifer is generally from the higher areas not connected to the contaminated zones. Finally, borehole sediment data from Bangladesh have shown that the highest soil contamination of arsenic is in the shallower upper areas. Of course, none of these hypotheses has yet been fully validated.

Table 2. Questions and answers about the migration of arsenic in groundwater.

Question	Answer
Has historical groundwater movement contributed to the spread of arsenic contamination?	Despite the very slow movement of groundwater, contaminants would spread significantly if no sorption were considered. Sorption will, however, occur and the sorption characteristics of the aquifer, which determine the retardation of arsenic, depend on the chemistry of the groundwater and the iron content of the sediment. Although retardation slows down the arsenic movement its spread can be significant over time scales of hundreds to thousands of years.
How is the mobility of arsenic affected by the hydro-chemical conditions in the aquifer?	The least retardation occurs in groundwater that has a high phosphate concentration and that has a low pH, and that moves through sediments with low iron content. A low phosphate concentration, a high pH and a high iron concentration in the sediment cause very significant retardation, to the extent that arsenic at low concentrations migrates extremely slowly.
How do local variations in the permeability of sediments that are presumed arsenic hot spots affect the spread of arsenic through the aquifer?	If arsenic hot spots occur in low permeability horizons then the natural migration to more permeable sediments is extremely slow. Even after 50 years and with moderate retardation, the arsenic is effectively immobile. However, if the hot spot is penetrated by a tube well, migration is possible directly from the hot spot into the tube well.
How do local variations in the direction of groundwater flow impact on the migration of arsenic? One may consider the impact of rivers and local relief on arsenic movement in groundwater.	Local relief and rivers impact on the direction and velocity of groundwater flow and therefore on the migration of arsenic. Groundwater flow from high- to low-relief causes deeper penetration of contaminants into the aquifer. The reverse is hue in areas that are low in relief. Here upward groundwater movement would bring contaminants to shallower horizons. Near rivers, groundwater flow is often enhanced, although flow direction changes between seasons. This may lead to the establishment of diffuse zones of arsenic contamination such as observed near Faridpur town along the banks of the Kumar River.
How does groundwater abstraction for irrigation and water supply, which has been introduced in recent years, impact on the movement of arsenic?	Large-scale groundwater abstraction for irrigation has limited impact on regional groundwater flow velocity and will, therefore, not cause a dramatic change in the movement of arsenic in the aquifer. Tube wells that penetrate sediments, which contain arsenic in dissolved form, will obviously abstract the arsenic directly from these sediments.
What are the short-term risks of contamination of tube wells that currently yield uncontaminated groundwater?	Even within tube well command areas, arsenic migration is limited unless the arsenic is present very close to the well. The model findings indicate that the movement of arsenic in groundwater is slow, of the order of no more than a few meters per year. This indicates that tube wells that currently yield safe drinkine water are not at immediate risk of contamination.

Source: **BGS** and MML 1999.

Implications for Agricultural and Irrigation Policy

Groundwater containing arsenic is being used in Bangladesh for irrigating crops, mainly rice. There is concern over the possible accumulation **of** arsenic in soil and in the food chain. Normally, arsenic would tend to be quite strongly adsorbed in aerobic soils, but the situation in paddy soils is apparently more complex and less-well-understood. Plants themselves can provide barriers to heavy metal uptake by preventing the translocation from root to shoot. While sufficient data do not exist as yet for conclusive evidence, some studies by the BGS and MML (1999) did come up with the following results:

- Arsenic concentrations decreased significantly along primary irrigation canals.
- Quite high concentrations of arsenic were found in the soil of paddy fields.
- Arsenic was found in the roots of paddy plants ***but*** not in the rice grain.

The possible influence of pumping is a key policy issue for the water sector. There is extensive withdrawal of groundwater for domestic use and for irrigation. Although, comparatively speaking, there are fewer irrigation wells than domestic wells pumping the groundwater, groundwater abstraction for irrigation accounts for 90 percent of the abstraction by volume (figure 5 shows the growth in irrigation over the period 1975 to 1995). The critical question therefore is whether or not groundwater pumping for irrigation is either creating or exacerbating the problem of arsenic in drinking water. Hypothetically, the influence could be that either the lowering of the water table or the through-flow of groundwater through the aquifers has a direct consequence on arsenic mobilization and/or transport. These hypotheses were tested as explained in the section on Arsenic Mobilization and Transport and the following conclusions can be drawn:

- There was no spatial correlation between areas of most intense arsenic contamination and the distribution of groundwater abstraction, and also the deepest groundwater levels.

- Even under conditions of low arsenic sorption, movement of arsenic might be in the order of 50 m in 15 years; therefore while irrigation wells may enhance the movement and dispersion of arsenic this effect is likely to occur over the time scales of decades.

- Enhanced fluctuation of water tables is *not* responsible **for** mobilizing arsenic

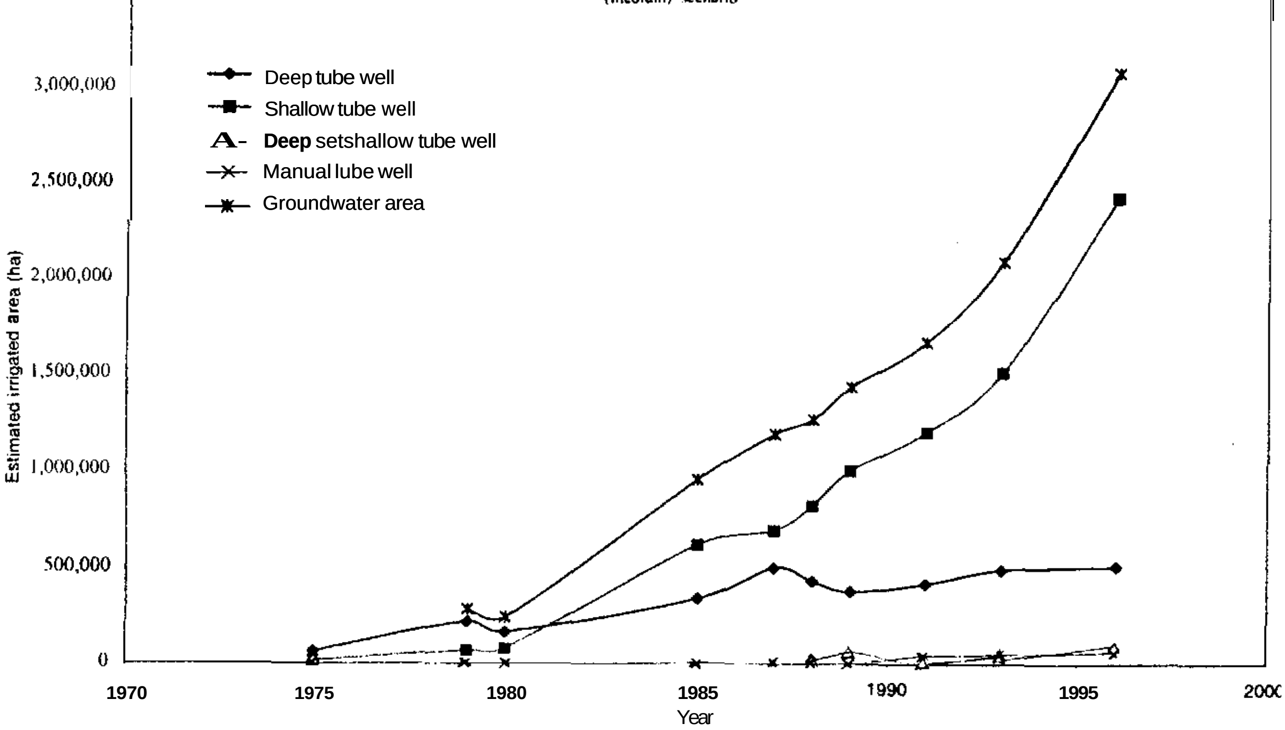
Ravenscroft (1999) hypothesized that continued abstraction of groundwater might even clear the aquifer of its arsenic content, as equilibrium concentrations of arsenic in the sediment and water phase are finite and will eventually have to be flushed out completely if pumping continues. This theory, of course, does not account for any arsenic that may re-enter the groundwater through the use or recycling of contaminated irrigation water.

Figure 5. Growth of groundwater irrigation.

Minor irrigation and groundwater abstraction in 1996

Number of thanas with data	464
Total land area	14,529,181 ha
STW irrigation	1,884,000 ha
DSSTW irrigation	67,000 ha
UTW irrigation	521,000 ha
Manual tubewells	51,000 ha
SW irrigation (LLP & traditional)	735,000 ha
Total minor irrigation	3,258,000 ha
Proportion of gross area irrigated	22 %
Proportion of rice in irrigated crops	83 %
Net abstraction	71 mm
Usable recharge (mean year)	459 mm
Usable recharge consumed	15 %

Notes The table excludes the Dhaka and Chittagong municipal areas. The recharge and abstraction estimates are area weighted averages. Recharge is based on the MPO 'Deep percolation Case 3 (medium)' scenario.



Note: Because of inconsistencies in data formats between different sources, irrigated areas have been estimated from tube well numbers using 1991 national average command areas for each technology. The graph therefore does not show true areas but is representative of long-term trends.

Source: **BGS** and MML 1999.

However, three aspects related to irrigation and irrigated water use need further investigation (BGS and MML 1999):

- The widespread use of "boro" (seasonal) rice provides just the conditions that would minimize air entry to the underlying aquifer and would therefore make any ongoing reduction and arsenic release that much more effective.

- The effect of phosphate fertilizer use. Phosphate concentrations in the groundwater are abnormally high (frequently higher than 0.5 mg/l as phosphate-P), and this could make the arsenic more soluble by competing for sorption sites as explained earlier.

- Possible entry of arsenic from contaminated irrigation water into the **food** chain and its effects on soil quality.

Ravenscroft (1999) and Kabir (1999) feel that a coordinated effort must be undertaken to study the fate of arsenic in the irrigation/agriculture cycle and the sustainability of food production systems with arsenic accumulation. Thus far, this aspect has received little attention given the overwhelming need to solve the domestic/drinking water crisis looming ahead. Many pertinent questions, such as a) Is there reduction between the levels of arsenic in the water at the well head and the root zone? b) Different crops accumulate arsenic differently and might these be related to the amounts of water required? and c) Arsenic may already be present in the soil in some of these areas and what is its contribution compared to the arsenic being distributed through the irrigation cycle? require answers. A conceptual model of the fate of arsenic in groundwater irrigation, which may have interesting possibilities if IWMI does get involved in the irrigation aspects of arsenic, is proposed (see figure 6).

Arsenic Contamination in Terrestrial and Aquatic Environments

General

Arsenic **is** widely used for a variety of purposes including the manufacture of pesticides, defoliants and herbicides, and in lesser amounts as a feed additive (in chick feed). Arsenic is widely distributed in soils, mostly combined with iron, nickel, gold, and sulphur. In **soils** it may originate from the parent materials that form the soil or from industrial waste discharges, irrigation waters contaminated from mining sources, and agricultural use of arsenical pesticides.

Arsenic is found in detectable concentrations in all soils. In uncontaminated, nontreated soils its concentration seldom exceeds 10 parts per million (ppm), but in agricultural areas where arsenic pesticides or defoliants are used, arsenic residues can accumulate to very high levels in soil (even as high as 600 ppm at the soil surface). In areas near natural arsenic mineral deposits, soil levels may average 400 to 900 ppm. Studies have shown that arsenic can move downward with leaching water, especially in coarse soils, Arsenic exists in several forms (both inorganic and organic) and oxidation states in the soil matrix. In strongly reducing environments, elemental arsenic and arsine (III) can exist, but arsenate (V) is the stable oxidation state in aerobic environments. Under moderately reducing conditions like flooded soils, arsenite (III) may be dominant. Arsenite is a common commercial form of arsenic and one of the most toxic arsenic compounds.

Arsenic is not an essential element for plant growth although stimulation of root growth has been observed with small amounts of arsenic in solution. Small yield increases have also been observed at low levels of arsenic in soils in tolerant crops such as corn, potatoes, rye and wheat. This type of plant growth stimulation does not always occur and may sometimes result in reduction of top growth. The uptake and translocation **of** arsenic (i.e., whether it remains in the root zone or migrates elsewhere) seem to be influenced by the source of arsenic (the chemical form or compound). Arsenic uptake seems to be passive from terrestrial soils to plants.

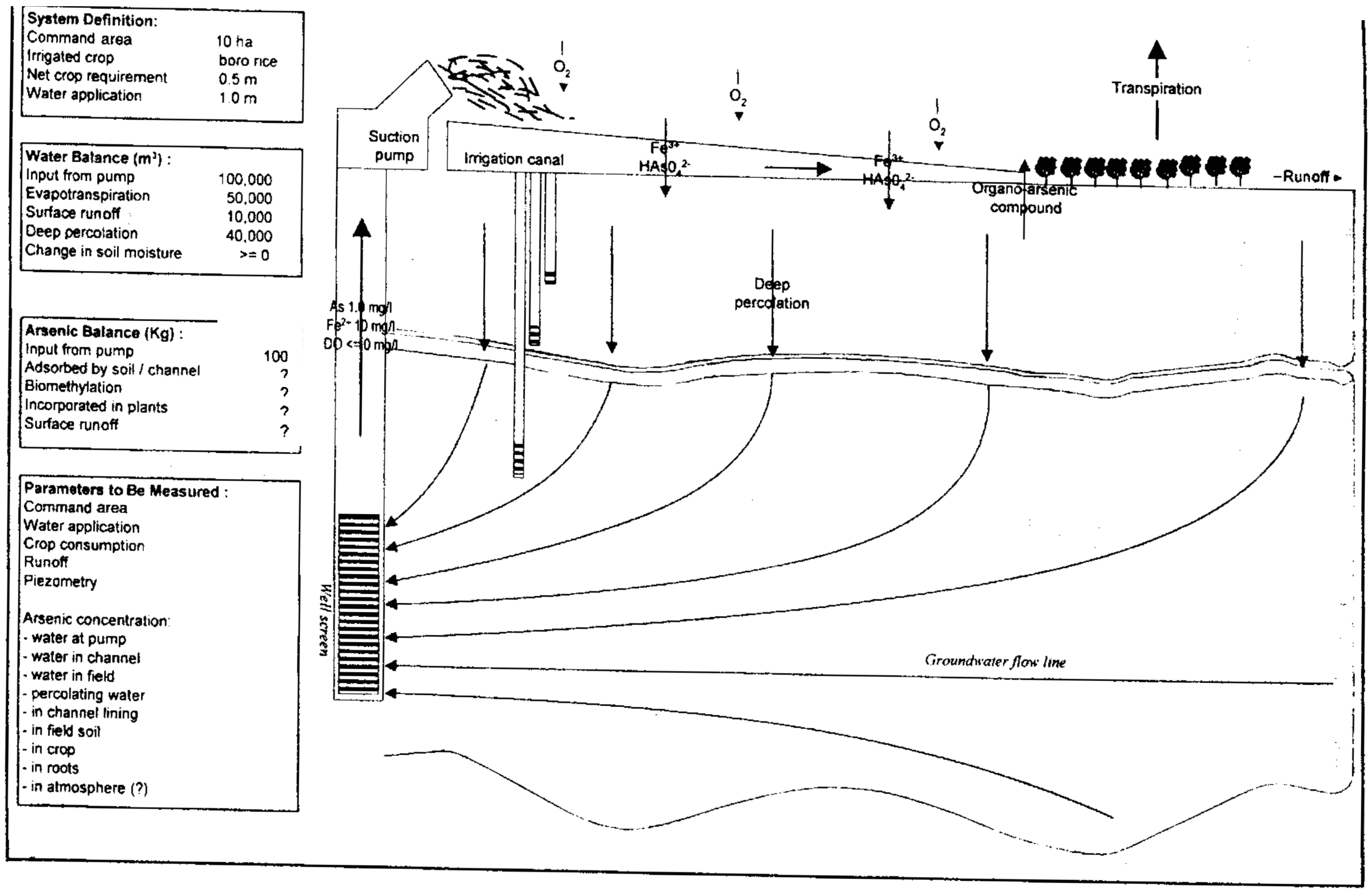
Crops have different degrees of tolerance to soil arsenic. Members of the bean family, rice and most legumes are fairly sensitive. Paddy rice is known to be very susceptible to arsenic toxicity as compared to upland rice, since the prevalent reducing conditions in rice paddies stimulate As (III) (which is a more toxic form) and Fe (II) production, resulting in a synergistic effect that would intensify toxicity. In Japan, irrigation of paddy fields with water contaminated by mining wastes has frequently produced growth depression in rice. FAO information indicates that paddy yield will be decreased by 20–30 percent if it is irrigated using water containing arsenic in concentrations between 0.01 and 0.05 mg/l. Water quality criteria for arsenic in wastewater used for irrigation purposes, from a few countries across the world indicate a variation in values ranging from 0.05 mg/l in some countries to 1.0 mg/l in others (Chang et al. 1996).

The major symptoms **of** phytotoxicity include wilting of new-cycle leaves, followed by retardation of root and top growth, sometimes accompanied by discoloration and necrosis of leaf tips and margins. In rice plants tillering is severely depressed. All these symptoms are indicative of a restriction in the movement of water into the plant, which may result in death.

The cycling of arsenic in an agronomic ecosystem is presented in figure 7. The figure has been modified by the author to show the possible transfers to and from **a** field for the organo-arsenical herbicides and arsenic from irrigation water.

In practice, ordinary crop plants do not accumulate enough arsenic to be toxic to man. In fact, they themselves die before the arsenic contamination in edible parts can achieve levels toxic to man. Instead, growth reductions and crop failure are the main consequences, and only small increases in the total arsenic content of crops are noted in contaminated as compared to non-contaminated soils. Edible

Figure 6. Conceptual model of the fate of arsenic in groundwater irrigation.

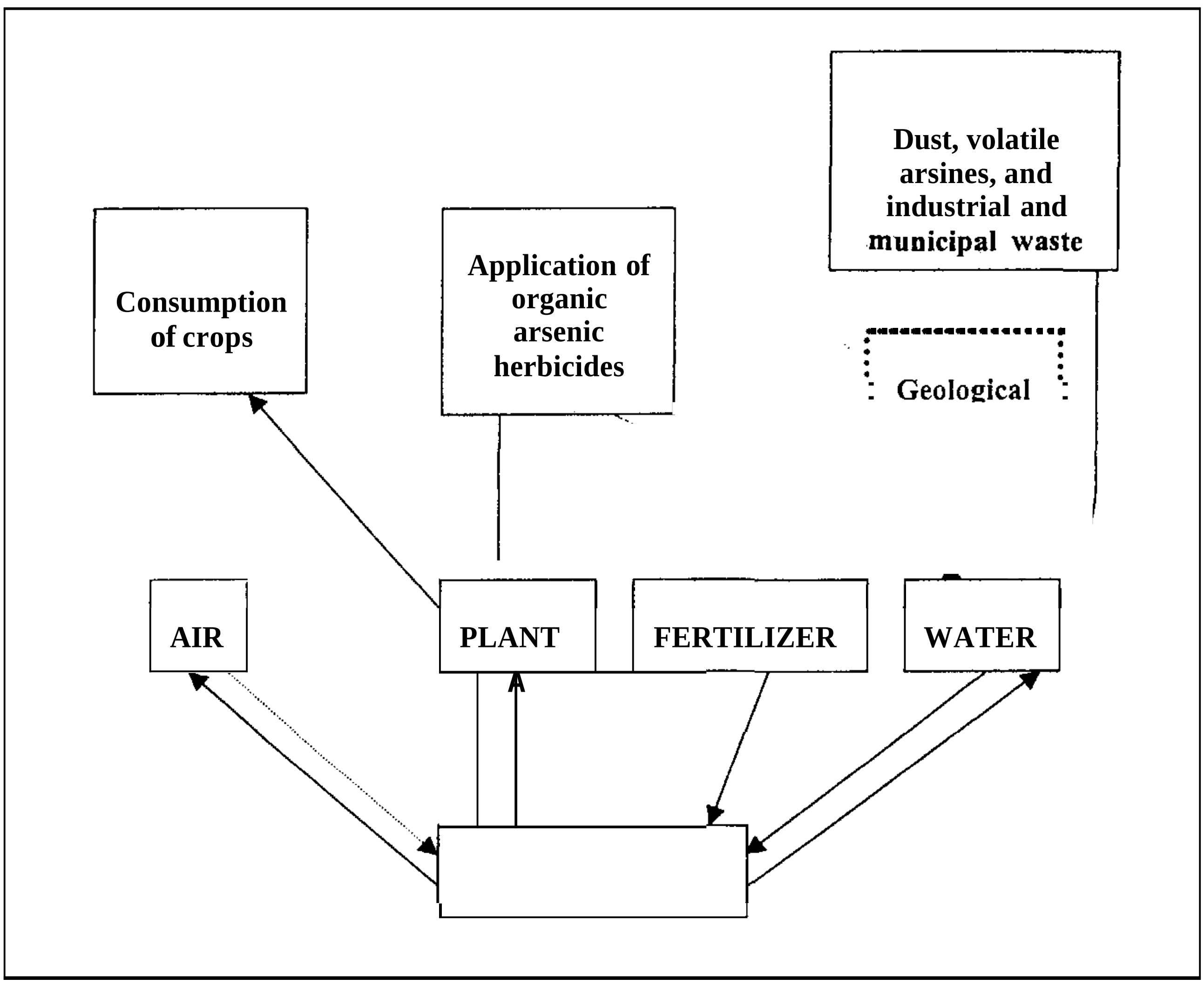


Source: Ravenscroft 1999.

portions of crops usually contain less arsenic than the other plant parts. Arsenic concentrations in plant parts were found to be below detectable levels (less than 0.02 ppm) in corn kernels and shelled peas. In potatoes, most of the arsenic was found in the peelings and was slightly above trace level (less than 0.1 ppm), even in potato flesh from plots treated with 720 kgiha of arsenic (Adriano 1986).

In an aquatic environment, waterborne arsenic is **known** to accumulate to high concentrations in some species. According to the National Imgation Water Quality Program Guidelines on Arsenic (US EPA), bioaccumulation of arsenic from water has been well-documented, but there is no evidence of magnification along the aquatic food chain.

Figure 7. The arsenic cycle in an agronomic ecosystem.



Source: Sandberg and Allen 1975 as appearing in Adriano 1986: Modified

In Bangladesh

Plant uptake of arsenic had not been studied in Bangladesh yet to any detailed extent (Ahmed 1999; Heijnen 1999; Haq 1999). WHO is collecting and compiling all available information on arsenic in plants. This will be released in December 1999.

Some rice samples had been collected by the Asian Arsenic Network and analyzed in Japan. Some samples of vegetables consumed in a well-known five-star hotel had been analyzed (Ahmed 1999) at the request of the hotel management, which was concerned about the reactions of tourists and visitors staying at the hotel. It is ironic that the leafy vegetables had high concentrations of arsenic (no exact figures were mentioned), and it is these same vegetables that arsenic-affected patients are usually encouraged to consume as some of the nutritional value of these is a good barrier against manifestations of skin conditions related *to* chronic arsenic poisoning.

A recent study (Haq et al. 1999) from Bangladesh in which about a dozen samples from vegetables grown in an area of severe arsenic contamination were analyzed, showed that arsenic concentrations ranged from 107 to 2,000 parts per billion (ppb). Edible vegetables were found to contain a very high amount of water-soluble arsenic. Universities and research institutes in Bangladesh recognize the importance of studying the impacts on rice crops and livestock (which are fattened on rice stalks used as cattle fodder). Other studies in Bangladesh (quoted by Shah 1998) in areas irrigated with water containing arsenic concentrations over 1.2 mg/l showed soil concentrations of arsenic up to 51 mg/kg.

Health Impacts of Arsenic

General

Human arsenic intake is usually associated with food, particularly with seafood. In an analysis of total arsenic in various food groups in Canada it was found that fish and shellfish had the highest concentration of arsenic per kg wet weight, i.e., about 400 times more that what is found on an average in beverages. Beverages contained the lowest concentrations ranging from 3–4.5 micrograms/kg wet weight. Cereals, dairy products and meat/poultry products were in the range of 25 to 30 micrograms. However, arsenic in fish, for example, is low-toxicity organic arsenic, compared to arsenic in drinking water, which is of higher toxicity because of its predominantly inorganic form.

Whilst as little as 0.1 mg/l of arsenic trioxide can be lethal to humans, arsenic toxicity depends on concentration and length of exposure. The early symptoms are various skin disorders; chronic arsenism can cause cancer of various organs amongst other things. In general, health effects from the ingestion of arsenic over a period of time can be classified under cancers (internal and skin), cardiovascular effects, dermatological, and neurological effects, and some other miscellaneous effects. Some epidemiological studies conducted in different parts of the globe, on health impacts of arsenic identified internal cancers of the bladder, liver, lungs, and kidneys, skin cancers, hyperkeratosis and hyperpigmentation, and certain neurological conditions such as amnesia and peripheral neuropathy, cerebrovascular conditions, ischemic disease, arteriosclerosis and diabetes, as conditions that result from arsenic exposure (Calderon 1999).

In Bangladesh

Some epidemiological studies in Bangladesh have revealed that 92.5 percent of the population exposed to arsenic concentrations in water of 0.2 to 2.0 mg/l are affected by arsenical dermatosis and hepatomagaly. Hussain (1999) explained that the effects of chronic poisoning in Bangladesh were not very well known. However, two stages of poisoning could be distinguished. In the early stages, the symptoms were blackening and hardening of skin of soles and palms. Leukomclanosis, white spots and carcinogenic effects characterized the latter stages. Common clinical symptoms of chronic arsenicosis among affected populations in Bangladesh were hypermelanosis on the chest, hyperkeratosis and hyperpigmentation in palms and soles and non-cirrhotic portal fibrosis. More unusual manifestations of arsenicosis here were sclerodenna-like lesions (rare), Blackfoot disease and carcinoma (Sheikhtar 1999).

Bhattacharya, Chatterjee and Jacks (1996) quote that significant accumulation **of** arsenic has been noted in the skin, hair, skin-scales, as well as in biopsy samples of affected persons. Sarwar and Ashrafuzzaman (1999) showed that 25 percent of the children tested in one study were affected by arsenic poisoning. In one study area situated about 30 km outside Dhaka in the Narayanganj district, the prevalence rate **of** arsenicosis on the basis of visible symptoms was 8 per 1,000 persons (Hussain 1999). Here, during a site visit the author saw a very young child (under 5 years of age) who was affected by arsenic poisoning.

There is no curative treatment for arsenicosis, only palliative. Reversal is possible in the early stages particularly in young children if taken off the arsenic contaminated water. Treatment is difficult. Only the dermatic conditions might respond to some form of medication. One such medication used Beta-carotene as the active ingredient (also used as a food supplement in many western countries), extracted from the blue-green algae spirulina. **A** hospital-based nonrandomized study of a sample of 50 patients representing all stages of arsenicosis, followed by an epidemiological survey where half of them received 3 g/day of spirulina in capsule form (to avoid bad taste) and the other half received placebo; showed, after one and a half months, that 29 of the patients had improved after treatment. A more detailed study is required to validate these results (Hussain 1999).

Below (table **3)** are some data relating to the skin and other manifestations of arsenic toxicity in Bangladesh:

Table 3. Manifestations of arsenic toxicity in Bangladesh.

Skin Manifestations	Percent
Melanosis (body)	87.4
Keratosis (palms and sole)	67.7
Leukomelanosis	35.5
Hyperkeratosis	38.7
Other Manifestations	
Conjunctivitis	6.3
Bronchitis	10.5
Hepatomegaly	2.2
Non-pitting edema	1.6
Bowen's disease	1.4
Skin Cancer	0.7

Source: Khan et al. 1997

Providing Water Supply Options in Arsenic-Affected Areas

In terms of strategic options, two possibilities exist, viz: avoidance of arsenic-contaminated water or treatment of the same before consumption. With the avoidance principle, sources of water can be uncontaminated groundwater from shallow dug wells in the uncontaminated zone, uncontaminated shallow tube wells (which though not so numerous still exist), or water from the deeper uncontaminated aquifer (which is a very costly option), or from infiltration galleries. Surface water is a possibility as well but this will have to be from protected ponds with pond sand filters, household filters, or solar distillation/disinfection for added safety. Rainwater harvesting is another possibility.

In terms of treatment, arsenic is more readily removable from water when it is in the As (V) form rather than in the As (III) form. Therefore, oxidation is necessary as a pretreatment to any removal process. A variety of methods and techniques exist for the removal of arsenic, which include chemical treatment, physical processes or biological methods. The choice of the method depends, amongst others, on the overall water chemistry, the availability of products and their costs, and the quantity of water to be treated. Generally speaking, treatment methods can be co-precipitation and adsorption processes, lime treatment, naturally occurring iron precipitation, use of sorptive media, ion exchange, membrane techniques, microbial processes, and chemical packages and filter cartridges. These may be large scale or small scale, depending on the costs of the technique used.

In any removal process, care has to be taken to make sure that any waste products containing arsenic from the treatment process are safely disposed of.

No universally accepted low-cost treatment method(s) have so far been retained, though a number of filter media are being tested and presented regularly to the Bangladeshi authorities mainly from foreign privatesector interests. Three possible low-cost remediation techniques for large-scale removal (Jacks et al. 1999) are:

- Auto-attenuation, which requires allowing the contaminated groundwater once extracted to stand for a period of time. During this time, a process of auto-oxidation of Fe (II) to Fe (III) takes place generating a favorable substrate with surface reactive sites for the adsorption of both uncharged As **(111)** and anionic **As (IV).**

- Laterite adsorption (particularly for the arsenate form), in a filter column or by direct mixing into the water.

- Artificial recharge of aquifers, which involves introducing an oxidizing agent like oxygen or nitrate that will change the redox potential so that arsenic is not mobilized.

For treatment options at household level, various researchers are testing new techniques and methods. Two such examples are the "Bucket treatment method" developed by the DPHE-Danida Urban Water and Sanitation Project in Bangladesh, and the Solar Oxidation method for Removal of Arsenic **(SORAS),** being developed by the research group for Water and Sanitation in Developing Countries based in the EAWAG, Switzerland. The former involves oxidation of As **(111)** to As **(IV)** using permanganate solution with subsequent co-precipitation with alum. The latter involves photochemical oxidation **(As III** to **As IV)** in the presence of citrate, followed by flocculation and precipitation, and is still under study.

The 18 District Towns Water Supply, Sanitation and Drainage Project is providing drinking water in some of the secondary townships (Cremers and Hanchett 1999). The source of water for these townships was groundwater that was usually high in iron content. In some of these cases, the water was also contaminated with arsenic. Removal of iron, using precipitation methods followed by sedimentation or filtration, is common with such waters. During this process a high percentage of the arsenic also gets removed. Whilst comprehensive data on the phenomenon are not being collected it is clear that the removal process is effective enough to provide arsenic-free water within the Bangladesh standards.

The Danida arsenic mitigation project is a one-year pilot study, started in March 1999, whose objective is to test, on a much larger scale, the two-bucket household level chemical treatment system described above, in addition to creating awareness and researching other possible options (Thogersen 1999). In the first phase ***of*** the study, piped water supply from deep groundwater for core areas and shallow tube wells for peripheral areas had been set up providing a 24-hour supply of treated water, the treatment comprising Fe removal and chlorination as an added precaution during distribution. The common shallow tube **wells** extract at depths of 10–15 m. An Arsenic Removal Unit (ARU) has also been developed with an automatic dosage mechanism, which can be attached to individual tube wells. Operation and maintenance of these units may however be problematical.

The Social Dimension of the Problem and Information and Communication Activities Undertaken

Over the last two decades, the population of Bangladesh has learned to reject surface water as unsafe and harmful. People have learned to trust and subscribe to tube wells. Though arsenic contamination of groundwater is widespread in Bangladesh, the notion of arsenic contaminated water is highly abstract to the vast majority of people. A survey commissioned by UNICEF shows that only about 14 percent of the rural population are aware of the arsenic problem. There exist some misconceptions about arsenic contamination and its outcomes, e.g., arsenic was confused with iron. Even the difference between pathogen-free and arsenic-free water was not clearly understood by the people. There is no immediate and visible cause-effect relationship that can be established, which might have helped to explain the consequences. All this makes the issue of dealing with this problem more complex. In the instances where people are somewhat convinced of the dangers of consuming arsenic-contaminated water, there is often no alternative source of safe water available, or else it is more expensive or labor-intensive having a further impact on women and girls who usually fetch water for domestic purposes.

Some of the other key findings about people's perception of the problem, which was tbe basis for developing the Bangladesh government's communication strategy on arsenic (DPHE-UNICEF 1999 a and b; Sarwar and Ashrafuzzaman 1999), are listed below:

- Field research confirmed that while there were wide variations in what people knew about arsenic contamination and its consequences for health, awareness levels were very low across groups. The level of awareness was relatively higher in those areas where some mitigation activities had been conducted.

- Generally speaking, the attitude to the arsenic threat was one of complacency. There was general resistance to change water consumption and water management behavior, e.g., people with safe wells were not disposed to sharing them with others who were not so fortunate mainly because of concerns regarding the careless use of pumps by others. There was also the issue of prestige—one's womenfolk could not be seen begging for water.

- In general, while there was concern and fear regarding arsenic in affected communities, there were no visible signs of panic. No active instances of social ostracism were observed in the UNICEF survey, but instances have been reported of affected persons being rejected by family and friends. In some areas, affected families were selling their properties and relocating. Whether this was because they were under pressure to do so is not clear from the report. Sometimes, due to ignorance arsenic-related skin disorders were being mistaken for leprosy and affected persons were shunned—children were prevented from attending schools and adults were debarred from social and religious functions. Victims were not even allowed to collect water from uncontaminated wells in the neighborhood.

Marriage and job prospects were nonexistent for the victims. In spite of this, affected communities did not generally see themselves as playing any role in arsenic mitigation.

- People were more predisposed to switch to a safe source of water if

  - It was familiar.
  - It did not contradict existing beliefs (e.g., drinking pond water that looked dirty).
  - It was economically viable.
  - It could be made available at the individual household level.

- Women were responsible for water collection and management but were constrained **by** restricted mobility and had limited access to information sources. Provision of safe water alternatives would need to take this into consideration.

- Testing of tube wells was conducted by DPHE tube well mechanics, who had not received any direct or formal training in the procedure. No standardized procedure was followed to distinguish safe from unsafe tube wells. If tube wells were found to be contaminated, no systematic or formal feedback was provided to owners.

- Some social factors that inhibit the ***defection*** of affected persons are listed below:

  - Belief that arsenic-borne disease is contagious and fear of being isolated and ostracized keep people from seeking medical attention.
  - Young women patients do not turn up for treatment because suspicion of contamination will affect their marriage prospects. Older women avoid treatment to safeguard their marriages. Lack of female medical personnel inhibits women in rural areas from seeking medical assistance.
  - Accumulation of arsenic may continue unknown to the victim as symptoms surface only after a certain exposure period, leading to neglect of the initial condition.
  - Lack of easy access to medical facilities further retards treatment, whilst medical teams deployed for the purpose do not take people's work patterns into consideration and thus miss a number **of** working-class victims.

A recent news article (ACIAR 1999), quoting Chakrabborty, mentioned the ***addictive*** nature of arsenic contaminated water thus adding to the complexity of the mitigation problem if this fact is substantiated. It appears that people used to drinking this water seemed to prefer it to uncontaminated water, and continued drinking such water by choice. The author did not come across this phenomenon during the field mission there; neither did the other medical personnel who took part in the visit to an affected area mention this fact. **In** contrast, at one site visited, there was a high degree of awareness of the problem and those who knew of the problem and who had an easily available alternative source preferred not to put themselves at risk. Some persons consumed arsenic-contaminated water even after they knew of the risks, but this was explained by the fact that they did not believe themselves to be at risk.

Remedial Measures and Institutional Mechanisms to Combat the Arsenic Problem

Various initiatives have been undertaken by concerned organizations to mitigate the arsenic problem to the point that there are a number of uncoordinated actions leading to wasteful utilization of resources. In February 1999, the Minister of Local Government, Rural Development and Co-operatives inaugurated a national conference to coordinate action on the arsenic-mitigation program. Authorities in Bangladesh are studying the feasibility of keeping one pond in each of the country's 68,000 villages reserved as a source of drinking water with purification facilities.

The World Bank is leading a special theme group of **UN** agencies (UNICEF, WHO, UNDP, and UNESCO), which has been formed to help address the arsenic crisis. UNICEF has increased its commitment to arsenic-mitigation activities (budget of US$3 million). From the time that the issue gained international attention in 1997, the World Bank and WHO have allocated US$32.4 million to resolve the problem, but they are now being accused of not having done anything concrete to help the victims.

A major initiative is the World Bank coordinated Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) set up with the objective of encouraging rational use of water resources in affected areas. Its intention is to put in place a mechanism using a community-based demand-driven approach that will enable people to make rational choices about the sources of water they wish to use. Nongovernment organizations (NGOs) will act as facilitators to this process with the community themselves taking the lead as entrepreneurs. It is intended to mobilize the village as the organizational unit rather than the different community groups, so that the final decision will be a unified one in relation to the village unit itself rather than the separate communities that might comprise the village. The villages would then have to show their commitment by paying a fee after which the Project would help them implement the decision. The objective is thus to create a national framework that would then be applied irrespective of the donor agency, in the different donor-funded project areas. The total project will be implemented by the Department for Public Health Engineering (DPHE) of the Ministry of Local Government and Rural Development and Cooperatives (Ministry of LGRDC) and coordinated by the World Bank on behalf of the participating donor agencies. **A** Technical Advisory Committee for the National Project (BAMWSP) was set up under the DPHE. The key players in this project are the two ministries, UNICEF and the World Bank. Experts from water and sanitation, health, NGOs, geologists, etc., are all represented on this committee.

Establishing a National Arsenic Mitigation Information Center (NAMIC) is part of this effort where the center will act as a clearing house for information in relation to possible mitigation options and contribute to a more rational decision-making process.

A National Steering Committee on arsenic was set up in 1993 as one of the first initiatives when arsenic became an international concern, chaired by the Secretary to the Ministry of Health. It does not appear to be very active or effective, and its location within the Health Ministry seems also to create some institutional tensions with the Ministry of LGRDC, which is actually implementing the National Project. There is a strong representation of medical and health persons on the committee with some local government representation as well. Public health inputs and other technical inputs are thus somewhat limited on the committee. It is accused of being rather inactive considering the very important role it should be playing in the arena. There is too much tension between the different government players and separation of roles and tasks **is** not clear, leading to some confusion and duplication of efforts. The government was inefficient in the use of available funds, and instead NGOs and some external support agencies (ESAs) were playing a key role in getting things done on the ground. Testing of wells was still regarded as one of the key needs.

Besides the National Steering Committee and the Technical Advisory Committee, the Government of Bangladesh has set up a Ministerial Level Steering Committee under the Prime Minister. Interestingly, the ministries dealing with water resources, irrigation and the environment are not involved in this action. When questioned about this, the Secretary to the Ministry of Environment stated that there were other ministries and departments better placed to handle the problem.

The WATSAN (Water and Sanitation) Partnership Project has been set up with a steering committee comprising CAW-Bangladesh, DASCOH (a Bangladeshi NGO responsible for the component Community Management), the Swiss Agency for Development and Cooperation (SDC), IDE (a Bangladeshi NGO responsible for the component Development and Marketing), the Regional Water and Sanitation Group, South Asia (RWSG-SA), the NGO forum (NGOF), and UNICEF. Fifteen local partner NGOs and other stakeholders including the Ministry of Health, the Department of Public Health Engineering, village development committees and the communities are working within this partnership, supported by various agencies providing technical inputs.

UNICEF has given itself the task of raising awareness and educating the population on arsenic.

The Danish and Dutch governments as described earlier have shown their commitment to mitigating the problem through the projects underway. Other donors and **ESAs** like the Germans and the Japanese have shown their interest to play a much stronger role to solve the problem. Individual researchers financed by different sources are **also** carrying out some isolated studies on trace metals in soils and fish biology in relation to arsenic.

IUCN Bangladesh is carrying out a study on water use and management by villages in 8–10 hydrogeological zones using a participatory process involving NGOs. Other NGOs playing **an** active role are the GRAMEEN Bank, and the Bangladesh Rural Advancement Committee (BRAC), one **of** the few NGOs worldwide that has a large outreach.

Scientists from Australian Commonwealth Scientific and Industrial Research Organization (CSIRO) have assembled an international team comprising, in addition to themselves, persons from the Ballarat University (Australia), Kalyan University (India), and Dhaka University (Bangladesh). After investigating arsenic exposure pathways and possible routes of arsenic ingestion, including the impact of arsenic in quality of crops and phytotoxic effects, the team will develop strategies that will reduce or eliminate the **risk** of arsenic exposure.

Concluding Remarks

Initially, this study was not conceived as such a broad-based one, but as the author studied the issue it became apparent that unless one looked at the overall picture, it would be difficult to adopt and support the arsenic problem. This discussion paper was aimed at consolidating findings from current literature on the arsenic issue in Bangladesh and to supplement these findings through a field mission. During the field mission, the discussions conducted were always open and fruitful; and many useful ideas were exchanged and contacts made.

On the basis of these findings, it is possible to recommend that there is scope for a comprehensive, holistic study on the impacts of arsenic on the irrigation/agriculture cycle. Such an approach has not so far been undertaken and most initiatives relating to arsenic within the irrigation or agriculture cycles have been focused on a single aspect. Such studies, whilst being useful, cannot predict the consequences or project the impacts, for which an integrated approach involving a multidisciplinary team will have to be applied. In this regard, IWMI's comparative advantage in all things related to irrigation/agriculture could be put to good use.

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