

Arsenic Pollution in the Ground Water in Bangladesh: An Overview

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Abstract: Arsenic contents of surface sediments vary in the range 6-40 mg/kg; fine sand and sediments tend to have higher levels of arsenic than coarser fractions. From the mapping done so far about 60% of area in Bangladesh is affected by the arsenic problem. Of all the tried and tested methods of arsenic removal, adsorption-filtration seems to be more cost effective and user-friendly. Comparative studies indicate that filters made of hydrated ferric oxide (HFO) based porous materials are by far the most efficient filters and also the safest. Since Bangladesh has very large number of rivers, arsenic is likely to show up its presence in environment where rivers are very active.

Key words: Arsenic, Bangladesh, population, water, disaster.

Bangladesh is mostly a flat deltaic land formed by the motor action of the great Himalayan rivers: the Ganges, Brahmaputra and Meghna and comprises an area of 54,000 square miles. The surface sediments have generally a composition of silica sand of varied grain size, aluminosilicate minerals and organic matters (1-9%). Hydrated oxides of iron (iron oxyhydroxide) are associated with fine sand and clay minerals. The crystalline suspended matter in the rivers has an average composition 40% mica, 20% quartz, 20% chlorite and 10% fluorite. And the average chemical composition of the suspended sediment is as follows: Na 1.3%, K 6.5%, Mg 3%, Al 16%, Si 52%, Ca 3%, Ti 1.2%, Fe 13.5% (calculated to 100% without oxygen and hydrogen). Both the major rivers have chemical maturity of low order (1.3-2.4). Chemical maturity is a measure of the extent of exposure of the rocks to weathering processes in the drainage basin (Konta, 1985).

Arsenic content of surface sediments varies in the range 6-40 mg/kg; finer sands and sediments tend to have a higher arsenic concentration. The major rivers carry an annual average of 2.5 billion tons of sediment—much of it is retained inland by the following fluvial processes:

(a) Deposition on the floodplains, (b) Filling up of the numerous oxbow lakes, and (c) Formation of sand bars. The latter two processes in the active deltaic regions are so ubiquitous that one can scarcely fail to surmise that a sediment core leading up to 10,000 BP should clearly indicate the paleo fluvial dynamics of the coring site. Since the formation of oxbow lakes and their subsequent filling is a continuing and widespread phenomenon, the occurrence of peat and detrital organic matter at or near the surface is very common in Bangladesh.

Bangladesh is a monsoon drenched land. Average annual rainfall is 70 inches and most of the precipitation occurs during the monsoon (June-October). Monsoonal floods are normal and necessary both for land formation and soil fertility but occasional heavy rainfall and simultaneous peaking of the discharges of the Ganges and Brahmaputra give rise to severe flooding; each one of the three such flood episodes in the last two decades covered nearly 80% of the land mass of the country.

Bangladesh seems to have an inexorable supply of groundwater. The shallow aquifer has an average depth of 80 feet with a seasonal variation of 2-8 feet while the deeper aquifer is located in the depth range of 200-800

feet. Due to heavy rainfall and the presence of many large rivers and their innumerable distributaries both the aquifers are regularly recharged.

Although fresh water, both from the surface and ground, has always been abundant in Bangladesh, the people here since time immemorial have been the victims in their multitudes of the water-borne diseases like cholera and typhoid. During the British colonial times hardly any measure was undertaken to extract safe drinking water by sinking shallow or deep tubewells. The number of hand driven tubewells, which draw water from shallow aquifers, was no more than a few thousand in 1947. Even in the seventies this number was less than half a million.

Growing public awareness and national programmes for safe drinking water supported by international agencies like UNICEF and WHO gave rise to a quantum jump in the number of shallow tubewells. By 1997, there were over eight million shallow and fifty thousand deep tubewells in the country. And Bangladesh was declared one of the few countries in the developing world where safe drinking became available to 100% of the population. Although arsenic is known to occur in both surface and ground water quite extensively under varied geographical conditions on a global scale, it is surprising that neither the government nor the international agencies bothered to look carefully for the presence of this deleterious element by proper monitoring. It is now reported that a British geological organization was given the contract for the assessment of groundwater quality, but it somehow failed to report the presence of arsenic. A lawsuit lodged in this regard by a concerned N.G.O., pending in a British court, has now been settled in favour of the said organization.

Arsenic in the ground water of the Gangetic delta was first detected in the Indian state of West Bengal by the Environmental School of Jadavpur University in the late eighties and the concentration of the metalloid was found to be in the range of 0.05-2 mg/l (0.05 mg/l is generally regarded as the permissible limit). And a large part of this Indian State is affected by arsenic pollution. Since West Bengal and the western part of Bangladesh belong to the same Gangetic plain, grievous apprehension began to creep in the minds of the people of Bangladesh also. Due to scare mongering of both national and international print and electronic media, this concern quickly morphed into widespread fear. The very ground water which held the promise of at last protecting the entire population from mass death caused by water-borne diseases now seemed fouled and life threatening. No wonder the concerned environmental scientists without waiting for institutional support sprang, into action for monitoring both the extent of arsenic pollution and the health risk

posed by it to the population, understanding the pollution mechanism and finally for devising mitigative measures. Arsenic problem in Bangladesh is discussed in the following in the light of these endeavours.

Monitoring of Arsenic in Ground Water

Sample Collection

Unlike its congener phosphorous, arsenic is sensitive to redox conditions; the redox potential between arsenite, As(III), and arsenate, As(V), is only 0.53 ev. Hence care is exercised for samples in which speciation is determined. Flushing with nitrogen immediately after withdrawal from the aquifer and treatment with a few drops of HCl followed by measurement in the field laboratory yields reliable results. Arsenic has pronounced tendency to be adsorbed and desorbed by glass; therefore polyethylene bottles are used for sample collection. More often than not in sedimentary environment like that of Bangladesh, arsenic occurs with dissolved iron which is precipitated as hydrated oxides on contact with air; scavenging along with it whatever arsenic is present in the sampled water. A few drops of concentrated nitric acid is therefore added to suppress such coprecipitation (in case where total arsenic is to be measured).

Analytical Methods

For laboratory measurement of arsenic, there are several methods available. In spectrophotometric method arsenic in the water sample is reduced to arsine by acid-zinc followed by scrubbing through lead acetate impregnated glass wool and finally arsine is absorbed in either chloroform or pyridine solutions of silver diethyldithiocarbamate. The resulting colour intensity is photometrically measured at 535 nm. The method has a measurement limit of 0.01 mg/l but it can be pushed further down to 0.005 mg/l ppm by preconcentration and using cryogenic condenser. Arsenic is also measured by flow injection hydride generation atomic absorption spectroscopy and inductively coupled plasma mass spectroscopy; in these two methods sensitivity is about 0.002 mg/l. All these methods are used in Bangladesh. However, considering the cost and large number of samples, the rapidity of measurement and the need to screen samples above the permissible limit of 0.05 mg/l, spectrophotometric method is considered sufficient and is generally employed.

Rapid monitoring of a vast number of tubewells (10 million) is, however, far more challenging. The method adopted for this purpose must be reliable, low cost, user friendly and quick. After much trial, debate and debunking, field kits devised by the reputed German

company E-Merck has been accepted and is now being widely used for field monitoring. The E-Merck kit is based on arsine generation followed by colour development on mercuric chloride impregnated strips. It has a detection limit of 0.01 mg/l.

Macro and Micro Mapping

University research teams such as that of Environmental Research Laboratory of Jahangirnagar University, government agencies like the Public Health Department, N.G.Os like the Dhaka Community Hospital have been involved in countrywide monitoring. In addition, under a British technical assistance programme, Mott-Macdonald company and British Geological Society was given a contract for Groundwater Studies for Arsenic Contamination in Bangladesh, the mandate of which was to collate data and reports produced by various research and working groups. The four volume reports thus produced are fairly comprehensive and reliably describe the work done in this respect up to January 1999 (Phase 1, Ravenscroft, 1999). A report of Phase 2 has also been published but this seems to have taken other

considerations into account and is poorly repetitive of the Phase 1 report.

From the results of monitoring operations, it is now known that about 60% of the land area of Bangladesh is affected by arsenic (Figure 1).

The paleistocene terrace of Madhupur occupying about middle of the country, the hill districts of Chittagong on the eastern borders and a part of the moribund delta seem to be free of arsenic. Arsenic has been found in significant concentration in a localized area of northern moribund delta. On the macro scale, the occurrence of arsenic in affected region looks random and scattered and no pattern can be discerned in the concentration field of the geochemical map. However, if systematic and intense monitoring is done over a smaller area by taking a hot spot (high arsenic concentration) as the areal reference, then distinct patterns can be seen in both the drainage basins of the Ganges and Meghna (Figures 2 to 4).

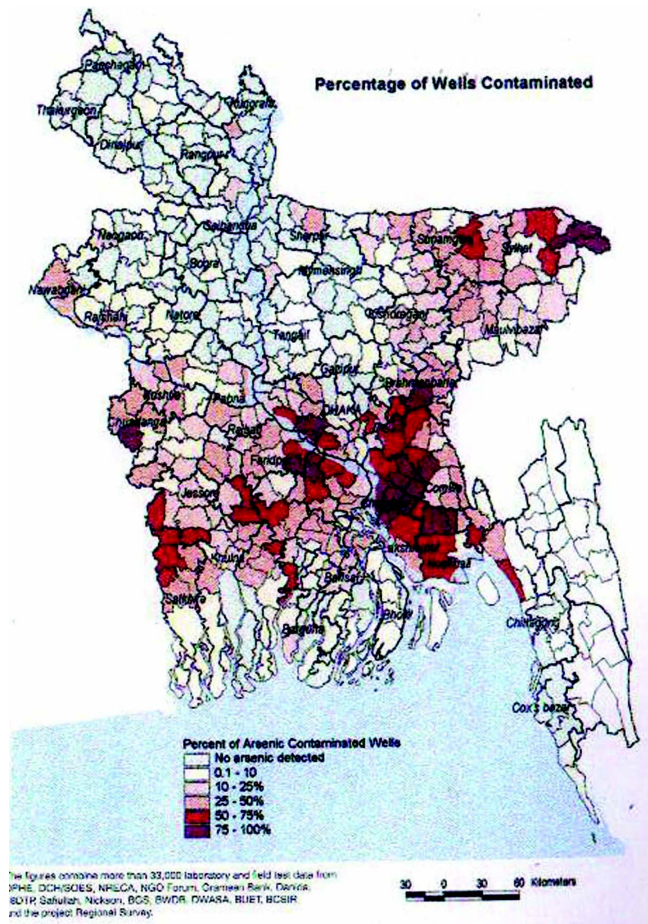


Figure 1: Arsenic affected areas of Bangladesh.

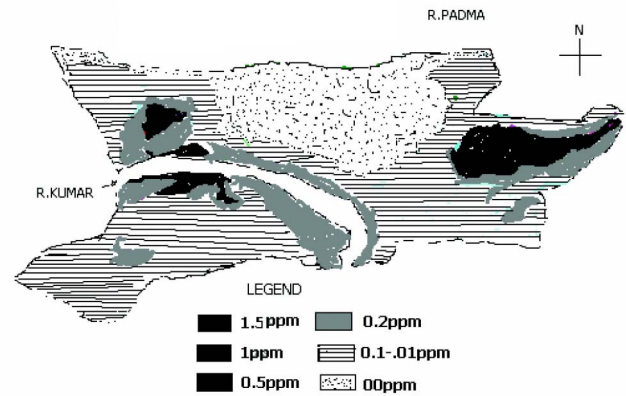


Figure 2: Micromapping of arsenic in a small area of the Gangetic basin, Faridpur Municipality.

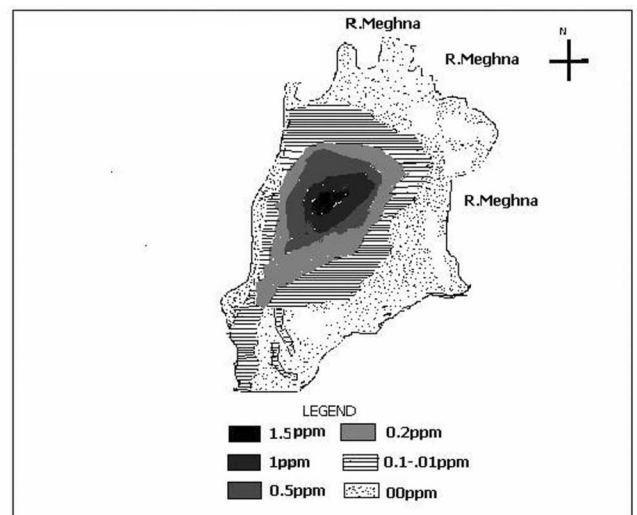


Figure 3: Micromapping of Arsenic in the Maghna basin, Sonargaon.

As(III) has been found in the range of 62-40% while As(V) has been found in the range 60-30% (Figure 5; Ravenscroft, 1999; Safiullah, 1998; Safiullah, 2001). About 96% of the contaminated wells are located in shallow aquifer (depth: 70-170 ft). Less than 1% of the contaminated wells draw water from the deep aquifer (depth: > 500ft). Contaminated deep aquifer wells rarely register concentration above 0.2 mg/l. In one case (Faridpur Municipality Area), it is suspected that the deep aquifer is contaminated by seepage of arsenic from the overlying shallow aquifer due to very high pumping capacity of the wellhead.

Mechanism of Arsenic Mobilization in Ground Water

At the beginning of arsenic alert, the Environmental School of Jadavpur University quite emphatically put forward the Oxidation Theory. The essence of the theory is that the arsenopyrite present in aquifer sediment is oxidised releasing both sulphate and arsenate in the ground water. On the other hand, the Environmental Research Laboratory, Jahangirnagar University, Bangladesh's Environmental School, Niigata University, Japan; and the Department of Geology, University of London, England (Safiullah, 1998; McArthur, 2001; Anawar, 2003; Tareq, 2003) found the following evidences to the contrary. And these evidences support a reduction theory.

- (a) The dissolved oxygen content of ground water is very small.

- (b) The redox potential of ground water was found in the range -102 - 235 mv indicating a reducing environment in the aquifer. Figure 6 shows the stability of As(V) and As(III) in various redox conditions.
- (c) Ground water is very low in sulphate content (occasionally below detection limit). Sulphate is a byproduct of pyrite oxidation.
- (d) Arsenic speciation measurement (Figure 7) shows that As(III) is present in the range 40-62%. It is difficult to surmise how redox sensitive As(III) could remain in an oxic environment.
- (e) Both the ground water and aquifer sediment have a high content of labile organic matter for facilitating reduction.
- (f) Bicarbonate, a product of the biogeochemical redox reaction, is significantly present in ground water and has a good correlation with arsenic (Figure 8).
- (g) Ammonium ion, a product of peat fermentation, has a significant presence.

Based upon the above mentioned facts it was surmised that arsenic is released to the ground water from the sediment due to reduction of the solid state carrier phase of arsenic, FeOOH , by organic matter (Bhattacharya, 1997; Nckson, 1997; Safiullah, 1998). Later on, by observing the significant presence of ammonium ion and correlation of ammonium (Figure 9) and bicarbonate with arsenic it was further proposed that it is the biogeochemical reduction involving organic matter like peat that gives rise to mobilization of arsenic from the solid to the aqueous phase (McArthur, 2001; Safiullah,

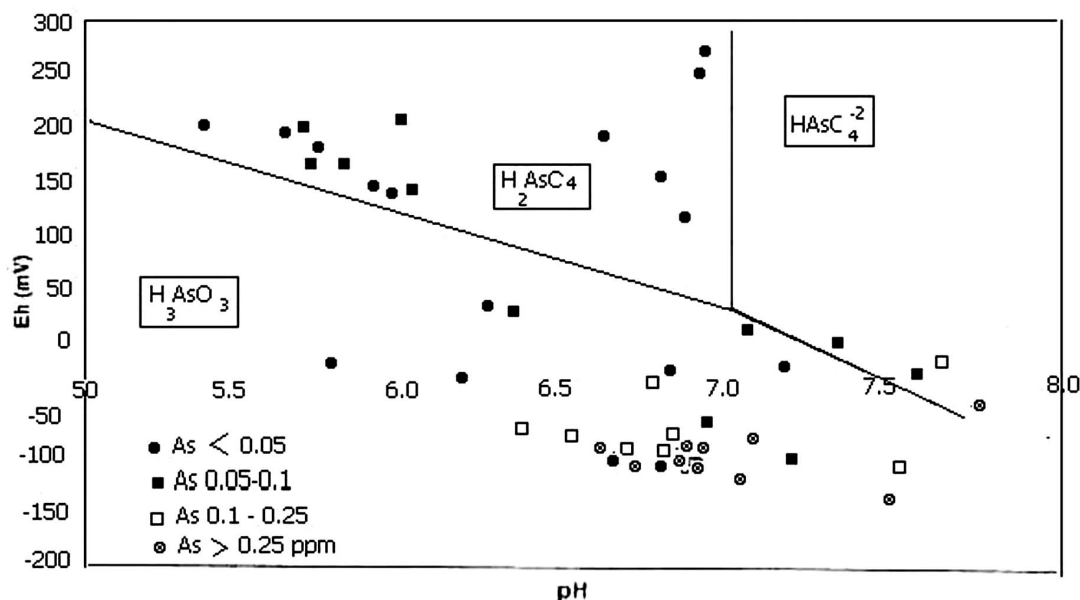
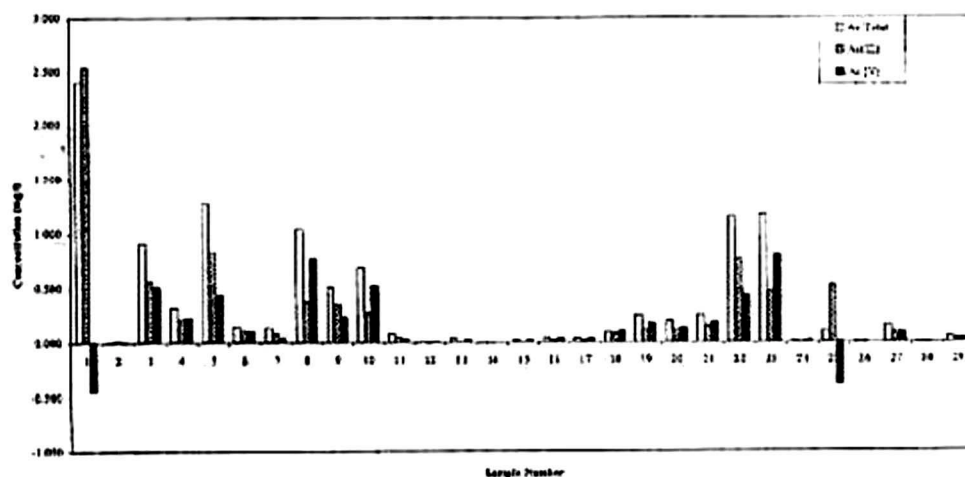
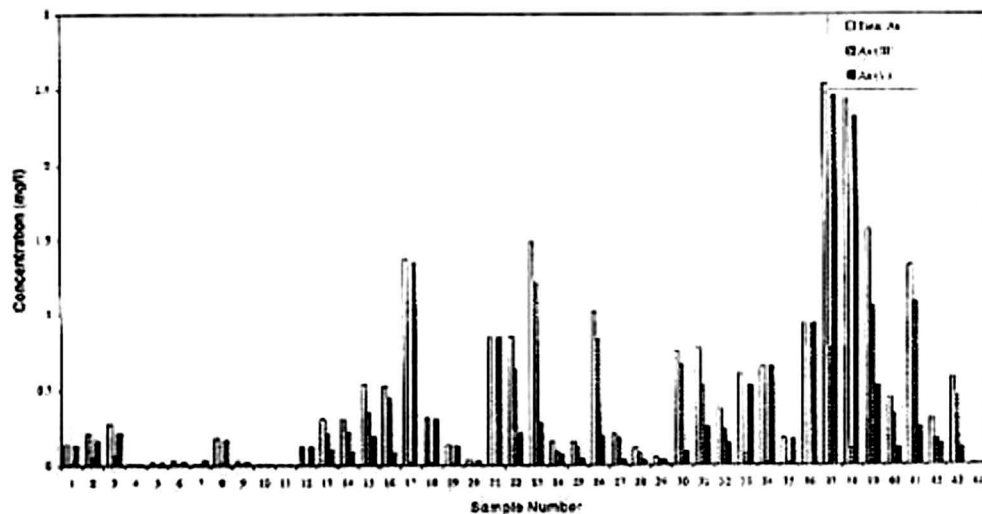


Figure 6: Redox diagram of Arsenic with respect to pH.

(a) Chapai Nawabganj groundwater (BGS, 1997)



(b) Bangladesh groundwater (Talukder, 1997)



(c) Noakhali groundwater (DPHE/DANIDA, 1998)

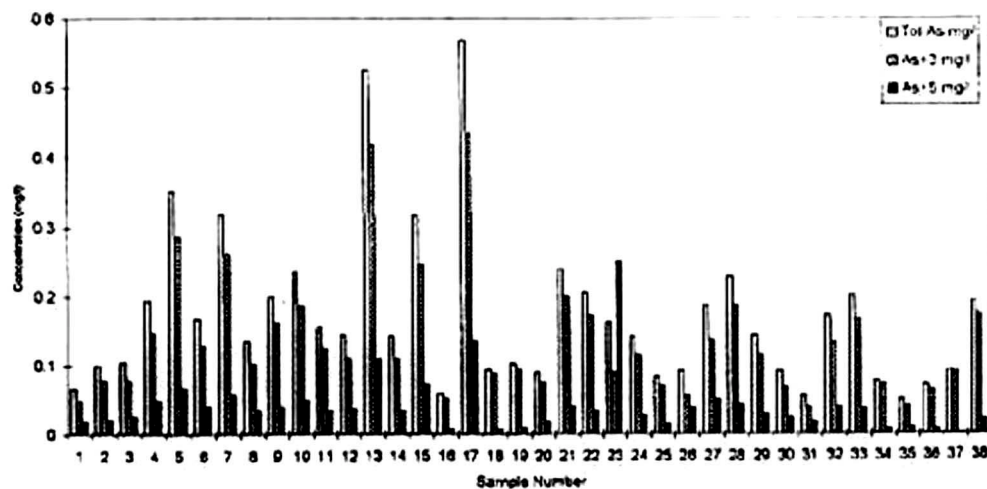


Figure 7: Speciation ratio of arsenic, in the ground water of Bangladesh.

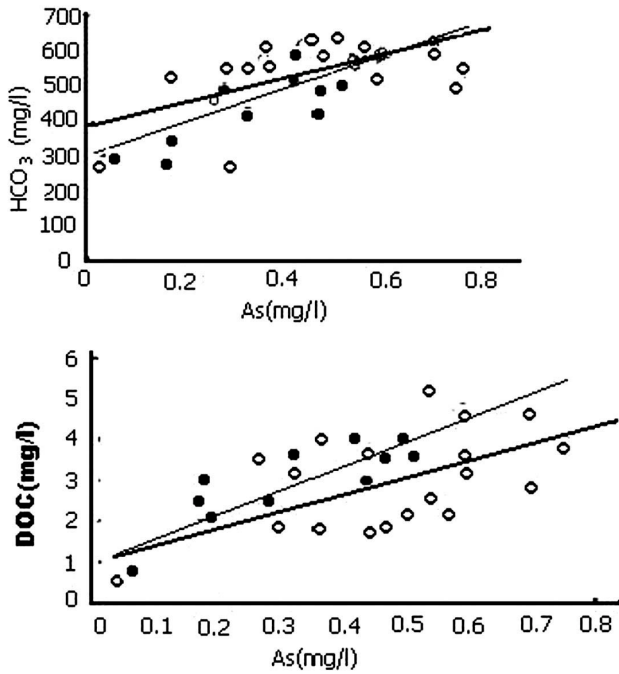


Figure 8: Correlation of arsenic, HCO_3^- , and dissolved organic carbon (DOC) in ground water.

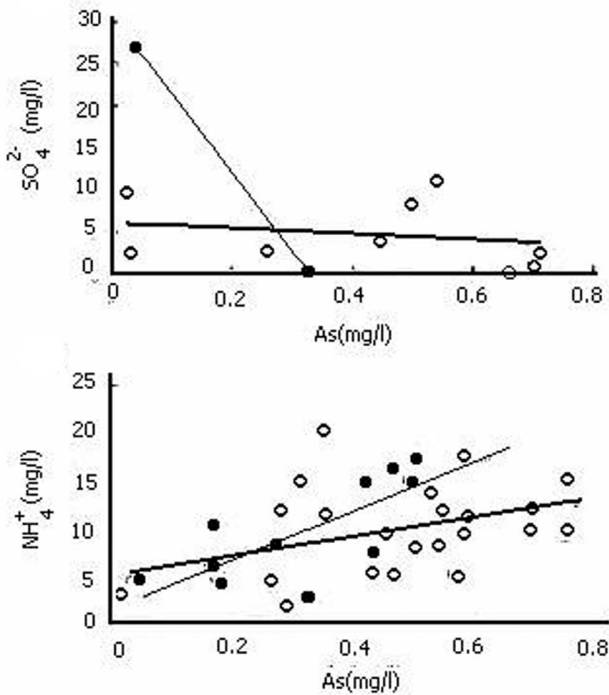


Figure 9: Correlation of arsenic, ammonium (NH_4^+) and sulphate (SO_4^{2-}) in ground water.

2003a). The measurement of redox change of the bacterial activity and subsequent release of arsenic from sediment in laboratory experiments was also observed (Figure 10, Anawar, 2003).

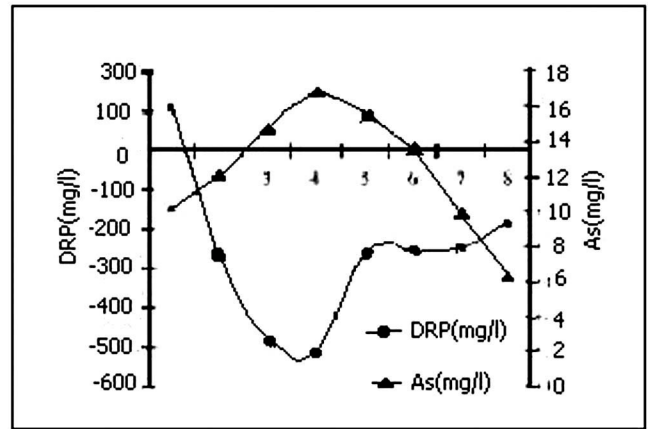


Figure 10: Biochemical redox of arsenic in ground water.

Leaching experiments with sediment show that common organic reducing agents like formaldehyde quite efficiently release arsenic in a linear way over a time period of 300 days (Figure 11) at pH 8.3, whereas at the same pH both hydrogen peroxide and molecular oxygen release some arsenic in a short span of time, after which release is either extremely slow or none at all (Safiullah, 1999). The rapid release of arsenic under drastic oxidative conditions probably indicates the radical change in the porous morphology of FeOOH . It has been shown that porous FeOOH absorbs arsenic by diffusion controlled chemisorption (Safiullah, 2003b; Safiullah, 2004).

The G-M-B deltaic shallow aquifer has been a poorly flushed system at least for the last 12 K years and the gradient of the floodplain is very small. This means that the biogeochemical profile of any site in the shallow aquifer has had little opportunity to be perturbed by hydrodynamic factors. This physical condition seems to be conducive for dissipative structures to emerge in the form of concentration of a particular element if both positive and negative feedback loops are present for the release of that element from sediment to water. The release of arsenic is likely to be significantly dependent on the pH of aquifer water. At low pH, As(V) will be attached to the binding sites but with the increase of pH competition with hydroxide ions will throw arsenic out of the binding sites. As(III) , carrying less charge, will tend to be even more soluble for the same reason. Reduction of As(V) either directly by organic matter or by bacteria using organic matter as a source of energy will therefore generally facilitate mobilization of arsenic. Deltaic sedimentary environment is particularly suitable for the biogeochemical transformation of organic matter.

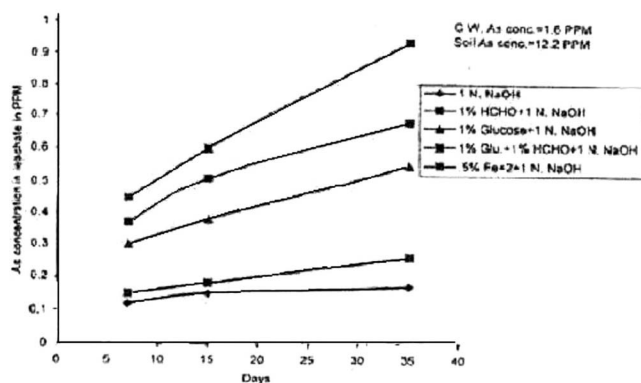


Figure 11 (a): Leaching of arsenic carrying sediment under various redox condition.

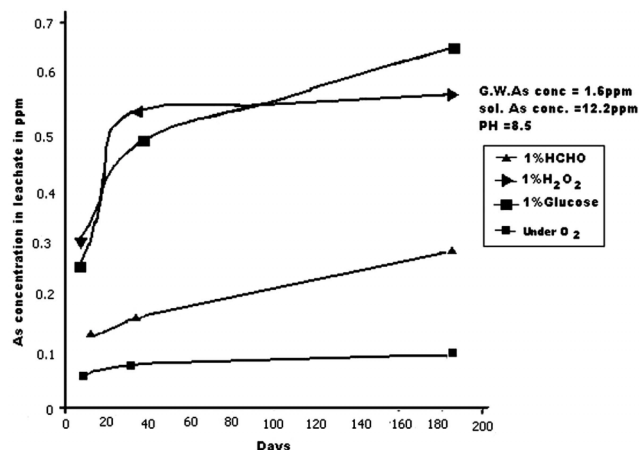


Figure 11 (b): Leaching of arsenic carrying sediment under various redox condition.

The higher molecular weight alkanes (C26-C29) have been used as reliable signatures of bimodal biogeochemical process taking place in Bangladesh floodplains (Ittekkot, 1985).

Mobilization processes:

1. $\text{FeOOH/As}^{+5} + (\text{CH}_2\text{OH})_n \xrightarrow{\text{Microbe}} \text{Fe}^{+2} + \text{As}^{+5} + \text{HCO}_3^-$
2. $\text{FeOOH/As}^{+5} + (\text{CH}_2\text{OH})_n \xrightarrow{\text{Microbe}} \text{Fe}^{+2} + \text{As}^{+3} + \text{HCO}_3^-$
3. $\text{As}^{+5} + (\text{CH}_2\text{OH})_n \xrightarrow{\text{Microbe}} \text{As}^{+3} + \text{HCO}_3^-$
4. $\text{FeOOH/As}^{+5} + (\text{CH}_2\text{OH})_n (\text{Labile}) \xrightarrow{\text{Microbe}} \text{As}^{+3} + \text{Fe}^{+2} + \text{HCO}_3^-$
5. $\text{FeOOH/As}^{+5} + \text{OH}^- \xrightarrow{\text{Microbe}} \text{FeOOH/OH}^- + \text{As}^{+5}$
6. $\text{FeOOH/As}^{+5} + \text{O}_2 \xrightarrow{\text{Change in Pore Structure}} \text{FeOOH} + \text{As}^{+5}$
7. $\text{FeOOH/As}^{+5} (\text{Solid}) + (\text{CH}_2\text{OH})_n (\text{Solid}) \xrightarrow{\text{Solid Phase Reaction}} \text{FeOOH/As}^{+3}$
8. $\text{FeOOH/As}^{+3} \xrightarrow{\text{Microbe}} \text{As}^{+3} + \text{FeOOH}$
9. $\text{FeAsS} + \text{O}_2 \xrightarrow{\text{Microbe}} \text{Fe}^{+3} + \text{As}^{+5} (\text{Not significant})$

Retention processes:

10. $\text{Fe}^{+3} + \text{As}^{+3} \xrightarrow{\text{Microbe}} \text{Fe}^{+2} + \text{As}^{+5}$
11. $\text{FeOOH} + \text{As}^{+3} \xrightarrow{\text{Microbe}} \text{Fe}^{+2} + \text{As}^{+5}$
12. $\text{FeOOH} + \text{As}^{+5} \xrightarrow{\text{Microbe}} \text{FeOOH/As}^{+5}$
13. $\text{MnO}_2 + \text{As}^{+3} \xrightarrow{\text{Microbe}} \text{Mn}^{+2} + \text{As}^{+5}$
14. $\text{As}^{+3} + \text{O}_2 \xrightarrow{\text{Microbe}} \text{As}^{+5} (\text{Not significant})$
15. $\text{As}^{+5} + \text{HS}^- \xrightarrow{\text{Microbe}} \text{As}_2\text{S}_3$
16. $\text{FeOOH} + \text{As}^{+5} + \text{HS}^- \xrightarrow{\text{Microbe}} \text{FeAsS}$

Adsorption-desorption processes involving organic matter:

17. $\text{Humic Acid} + \text{As}^{+5} \xrightarrow{\text{Microbe}} \text{Humic Acid/As}^{+5}$
18. $\text{Humic Acid} + \text{As}^{+3} \xrightarrow{\text{Microbe}} \text{Humic Acid/As}^{+3}$
19. $\text{Fulvic Acid} + \text{As}^{+5} \xrightarrow{\text{Microbe}} \text{Fulvic Acid/As}^{+5}$
20. $\text{Fulvic Acid} + \text{As}^{+3} \xrightarrow{\text{Microbe}} \text{Fulvic Acid/As}^{+3}$

Fermentation indicator:

21. $(\text{CH}_2\text{OH})_n/\text{N} \xrightarrow{\text{Microbe}} \text{HCO}_3^- + \text{NH}_4^+$

The arsenic species shown in the above mentioned reactions are of course all oxygenated (arsenate and arsenite). Tribasic nature of the arsenic acid makes the above mentioned equilibria even more involved. In all probability each of the single step reaction shown above has multiple equilibria. Intimate association of arsenic with organic matter in the same matrix as revealed by SEM studies (Ravenscroft, 1999), also gives rise to the apprehension of some solid state reaction taking place.

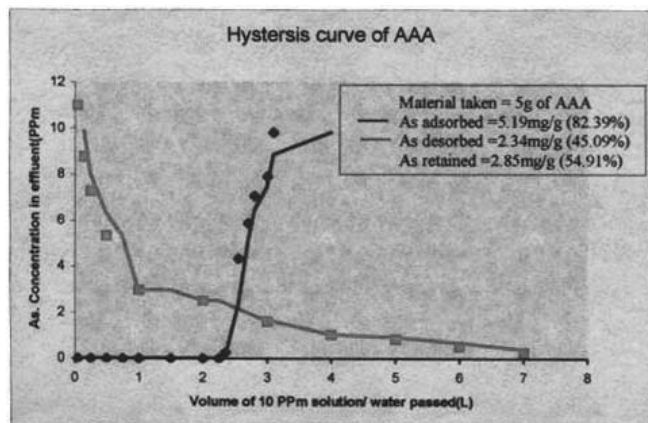


Figure 12 (a): Adsorption and desorption (at pH 7) curve of AAA for As conc in effluent vs volume of 10 ppm As solution/water passed

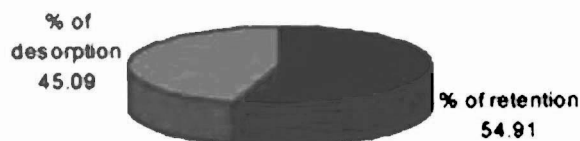


Figure 12 (b): Pie diagram for As desorption and retention capacity of AAA.

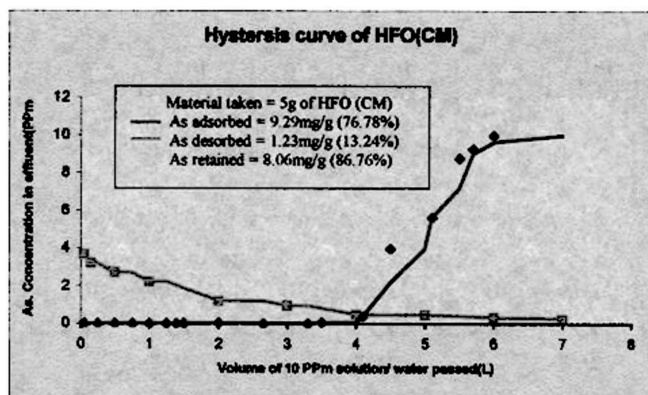


Figure 13: (a) Adsorption and desorption (at pH 7) curve of HFO (CM) for As conc in effluent vs volume of 10 ppm as solution/water passed

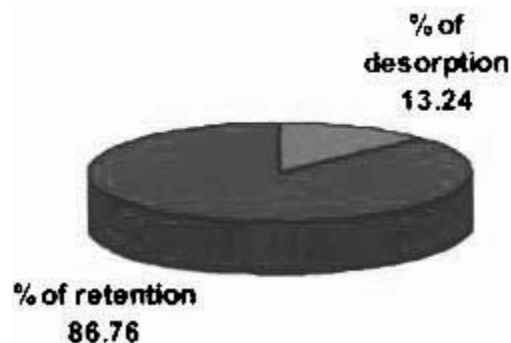


Figure 13 (b): Pie diagram for As desorption and retention capacity of HFO (CM).

The group of reactions comprising 1-9 would favour mobilization of arsenic from sediment to aqueous phase and therefore constitutes the positive feedback loop of the adsorption–desorption cycle of arsenic. The group of reactions comprising 10-15 seems to favour retention of the element in the sediment and constitutes the negative feedback loop. The ground water of both the Ganges and Meghna basins is known to contain significant concentration of humic acid (Safiullah, 1998; Ravenscroft, 1999). Fluorescent studies indicate that humic acid may play an important role in the adsorption–desorption equilibrium of arsenic (Tareq, 2003).

The amplification of the infinitesimal initial disturbance that initiates self-organization may be thought of, quite generally, as associated with a feedback. The simplest chemical feedback is autocatalysis whereby a given molecule promotes its own production. Most geochemical feedback is more complex, involving a number of variables; disturbances in these variables promote or suppress each other through coupled processes. Because the self-organization phenomenon (concentration of arsenic in aqueous phase) of interest here involves the redistribution of materials, at least two transport processes must be involved (adsorption and desorption at the sediment–water interface and diffusion through the pore channels of solid phase).

Thus we see that the final outcome of the concentration of arsenic at an aquifer location is due to complex inter-play of the above mentioned positive and negative feedback reactions. Therefore the concentration of arsenic at a given location is likely to be the result of a self-organized process. The presence of the highest concentration in water (2.4 mg/l) at far below the level of that in the sediment (5–25 mg/kg) indicates that there is somehow a check and balance to prevent run away release from the sediment to water. The presence of both As(V) and As(III) and lack of seasonal variation of arsenic

concentration and chemical speciation may be yet another indication of self-organizing process at work. However, much more work needs to be done before this hypothesis can be firmly established.

Health Risks Posed by Arsenic

Many studies have been done to determine how many people are already affected by arsenic pollution. One typical study shows that of the 11,180,000 people screened in 27 districts 2736,000 (24%) were affected with arsenical lesion (Chowdhury, 2000). It is estimated that out of a population of 140 million as many as 70 million may be at risk. Number of deaths actually caused by arsenic poisoning, however, remains under the haze of the ineptitude and corruption of the concerned government department, sounding of unnecessary alarms for project money by the N.G.O.s, spreading of panic by the local media and occasional subjective reportings in popular international scientific journals (*New Scientist*, 1999-2004; *Scientific American*, 2004). In all probability, no more than 5000 people have died during the last one decade; this, in no way, minimizes the gravity of arsenic calamity. The problem is both gargantuan in magnitude and grievous in character and implores all efforts to resolve.

The medical symptoms associated with arsenic poisoning are diffuse melanosis, spotted melanosis, leucomelanosis, diffuse keratosis, spotted keratosis, hyperkeratosis, mucus membrane melanosis, gangrene, skin, kidney, lung and bladder cancer.

The protocols for biological assay are described by Anawar et al. (2002). Results of several studies indicate that the lowest observed adverse effect level (LOAEL) for arsenic is 18 $\mu\text{g/kg/day}$ ($>0.2 \text{ mg/l}$) (Chakraborty, 1987). The lifetime risk of skin cancer is calculated to be 1.3/1000 for males and 0.6/1000 (Brown, 1989).

From various studies it seems that arsenic toxicity may be aggravated or diminished by the following factors:

1. Arsenic concentration in water and food, amount of arsenic intake from contaminated water and period i.e. nature, magnitude, frequency and duration of exposure.
2. Nutritional status and the capacity of the human to absorb arsenic deterring food such as animal and vegetable proteins.
3. The genetic variant of the human in response to arsenic exposure.
4. Synergistic and antagonistic effect of other elements and the dietary levels of other elements.
5. Age and sex of the exposed individual.

Constant intake of arsenic free water after exposure to arsenic has been detected, seems to be an effective first response. The poisoning action of As(III) takes place by interaction of this species with the sulphhydryl groups of enzyme proteins. Therefore intake of proteins and vegetables like brassica (cabbage, cauliflower, etc.) should help scavenging of arsenic before it can attack the SH groups of enzyme protein.

Mitigation of the Arsenic Problem

There are several ways of **removing arsenic from the contaminated water**; these are listed below.

1. Coagulation-precipitation followed by filtration.
2. Ion-exchange.
3. Reverse osmosis.
4. Adsorption-filtration.

In coagulation-precipitation, contaminated water is treated with a ferric salt in presence of an oxidant; simple aeration is sufficient on most occasions. If the water contains enough dissolved iron, which occasionally is the case, then good deal of aeration causes arsenic As(V) to coprecipitate with iron oxyhydroxides. The precipitate after being allowed to settle is removed either by decantation or filtration to obtain arsenic-free water. The method is in principle simple and efficient but not risk free, because there is possibility of arsenic-rich micro flocks being injected to cause more harm than good in the long run. Besides sludge disposal is a problem.

In principle both reverse osmosis and anion exchange resin should remove arsenic and have been found to do so from medium to low concentration solutions (0.1-0.5 mg/l). However, under the economic realities of Bangladesh, these methods are exorbitantly expensive. Using HFO impregnated cellulose acetate membrane and hand operation reverse osmosis systems have been devised. But they need further trials for successful implementation (Safiullah, 2003c).

Of all the tried and considered removal methods, adsorption-filtration seems to be more cost effective and user friendly. There are many macro and mesoporous materials that can remove arsenic from solution. Porous and mesoporous hydrated ferric oxide (HFO), HFO-coated silica and silicate materials, activated alumina, HFO coated activated alumina (AAA), titanium dioxide, activated charcoal and chitosan from crustacean shells are some of these materials (Safiullah, 1999). Of these, the HFO-based materials remove arsenic by diffusion-controlled chemisorption. Kinetic of adsorption shows that the entropy of reaction ΔS and the free energy of activation E_a are -271 KJ/mole and 85 KJ/mole,

respectively, while the diffusivity D_f is $1.5 \times 10^{-7} \text{ cm}^2/\text{s}$. On the other hand, porous materials like activated alumina and charcoal remove arsenic from the solution by physical adsorption (Safiullah, 2003b; Safiullah, 2004). The hysteresis curves of HFO and AAA in Figures 12 and 13 show that very little arsenic is released from the arsenic loaded HFO materials (13%) whereas from the arsenic loaded AAA based materials, 60% arsenic is desorbed. Leaching experiments show that arsenic adsorbed on HFO is not released up to pH 11 (Safiullah, 1998).

Comparative study of the efficiencies of bed filters, made of different absorbants and having filtering capacity of 1000 litres per day, shows that the filters made of HFO-based porous materials are by far the most efficient and the safest. A typical locally manufactured, HFO based, SAFI filter has a breakthrough volume of 60,000 litres at arsenic concentration of 1.6 mg/l whereas the AAA based Alcan filter manufactured by a Canadian Company has a breakthrough volume of only 1500 litres at the same concentration and flow rate (Safiullah, 2004).

Figure 14 gives a graphical account of the performance profiles of various arsenic removal filters now in operation in Bangladesh. It is curious to note, however, that the government agency BCSIR, entrusted with validation of arsenic removal filters awarded a validation certificate to the Alcan system apparently without rigorously checking its performance. The same agency created quite a bit of sensation at the beginning of arsenic alert by reporting a sample of 14.3 mg/l concentration measured by AAS method, which later on turned out to be 1.5 mg/l, less by an order of magnitude.

On the basis of its removal efficiency, HFO coated porous silicate material (10 kg) was packed in the strainer column of a especially designed shallow tubewell with an arsenic concentration 1.4 ppm. The tubewell was continuously run with a draw load of 400 L/D for six months and monitored. During these six months of operation the tubewell yielded water with arsenic concentration in the range 0.1-0.01 mg/l (Safiullah, 2004). It was interesting to note that the freshly sunk tubewell did not register its equilibrium arsenic concentration (1.4 mg/l) all at once but took about a week to do so. This again reminds one of self-organization at work.

During the installation of the well, vigorous mechanical disturbances allow considerable amount of atmospheric oxygen to come in contact with the aquifer which then suppresses the dissolved arsenic concentration. After the installation of the tubewell there is much less scope of aeration of the aquifer and an equilibrium contact is established soon to allow sediment–water interface to work its way for attaining the destined As concentration.

Quest for Arsenic Free Water

Arsenic-free fresh water has been sought to be obtained from rain water, surface water by making sand ponds and deep aquifer.

Rain Water and Sand Ponds: In the wake of arsenic fear, government agencies aided by international organizations went in for rain water collection with contraptions of various sizes and shapes. The result of this endeavour, to say the least, is a fiasco. First of all,

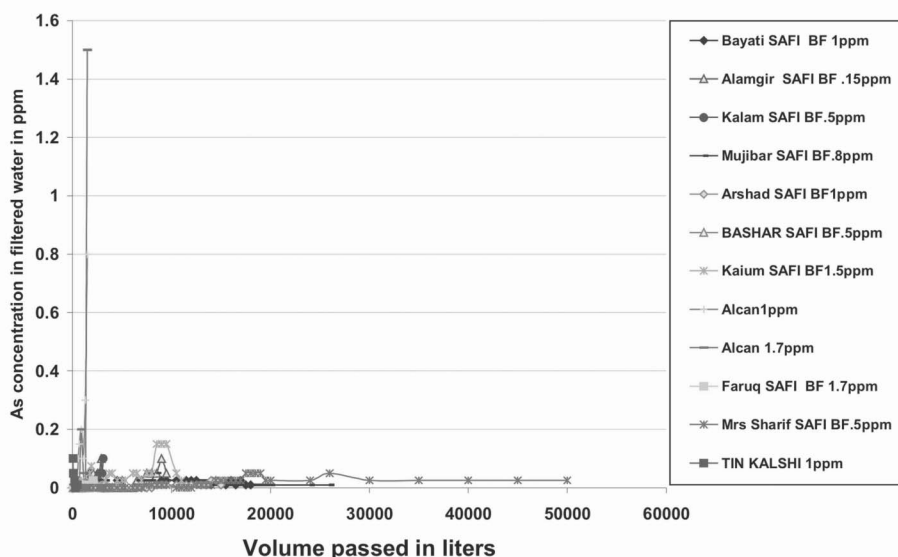


Figure 14: Comparative performance profiles of various validation tests based on arsenic systems.

the collection tanks soon became a veritable habitat of pathogens of all kinds and secondly the decomposition of organic matter gave rise to such obnoxious smell that people were most reluctant to use the collected rain water even for household purposes. Same can be said about the sand ponds. Being utterly exposed, they are vulnerable to pathogenic attack from washed in water, biological vectors and air borne bacteria.

Extraction from the Deep Aquifer: Thus far the deep aquifer has been found to be generally free of arsenic but it remains to be seen how a deep well responds to excessive drawing of water. Seepage from the overlying contaminated shallow aquifer is a potential problem; at least in one case such seepage was observed (Safiullah, 1998). Installation of deep well is more expensive by an order of magnitude, therefore such wells have to be community based with elaborate transmission system, imposing yet another cost barrier. Besides, the user loses some control over the source of water.

Geochemical Mapping

We have mentioned that detailed mapping around a hot spot in the Ganges and Meghna basins gives a pattern of the concentration field of arsenic in the aquifer. By examining such a map one can find out the arsenic-free zones even in a severely affected area. Recently a shallow well was installed with the help of such map (Figure 4) in a severely affected area and this well is yielding arsenic-free water for the last one year (Safiullah, 2004).

Some Concluding Remarks

There is a big crisis of fresh water looming large over mankind in this century. Yet by all accounts Bangladesh has a seemingly inexhaustible reservoir of fresh water in its aquifers. But this is, for now, largely fouled by the presence of arsenic. This offers both challenge and opportunity for local and international scientific community. Unfortunately, some initiatives and endeavours regarding the arsenic problem have been misdirected and bungled, with good deal of patronage of the local government agency and international organizations, by not so knowledgeable experts. Sensing the prospects of financial gains, vested interest groups from home and abroad have also pitched in firmly on the arsenic arena. There should be an end to this sorry state of affairs.

In all probabilities, arsenic is likely to show up its presence in any sedimentary environment where the rivers are active. Therefore arsenic, in all its ramifications,

should attract the attention of the global scientific community. The mobilization of arsenic, as far as it has been studied, is a very complex process and should create more scientific curiosity to resolve once for all how the metalloid is polluting the aquifers and thereby threatening to deprive humanity of one of the finest and largest sources of fresh water.

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