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Investigation of the efficiency of existing iron and arsenic removal plants in Bangladesh

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ABSTRACT

Arsenic in groundwater above 0.05 mg/l was found in 61 out of the total of 64 districts, and 433 out of the total of the 496 thanas in Bangladesh. Groundwater arsenic contamination in Bangladesh is reported to be the biggest arsenic calamity in the world in terms of affected population. Water in around 65% of the areas of Bangladesh contain iron in excess of 2 mg/l, and arsenic has been found to co-exist with iron in many situations. Thus the presently used iron removal plants that operate on the principle of aerating ferrous iron to convert it into ferric iron for precipitation can be a cost-effective solution for treating both iron and arsenic together in the context of Bangladesh. This study investigates the efficiency of 60 arsenic and iron removal plants (AIRPs) presently operating in different geo-hydrological conditions of Bangladesh.

Key words | arsenic, groundwater, removal plant

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ARSENIC CONTAMINATION OF GROUNDWATER IN BANGLADESH

Arsenic (As) contamination of groundwater is a major concern in many countries of the world such as Argentina, Bangladesh, Canada, Chile, China, England, Ghana, Greece, Hungary, India, Iran, Laos, Mexico, South Africa, Taiwan, Thailand, USA, Vietnam and Zimbabwe. Although arsenic contamination in groundwater been reported from various parts of the world, the single largest groundwater contamination so far has occurred in the Bengal delta, mostly in Bangladesh (Figure 1) and in part of West Bengal (India).

Groundwater arsenic contamination in Bangladesh is reported to be the biggest arsenic calamity in the world in terms of affected population. The Government of Bangladesh (GOB) has addressed it as a national disaster. Arsenic contamination of groundwater in Bangladesh was first detected in 1993. Further investigations were carried out in the following years. The institutions that contributed to the investigations are the School of Environmental Studies (SOES) from Jadavpur University in Calcutta, Bangladesh Atomic Energy Commission (BAEC), Dhaka Community Hospital (DCH), Department of Public Health Engineering (DPHE), and National Institute of Preventive and Social Medicine (NIPSOM). DPHE collected and analyzed 31,651 well water samples with the assistance of WHO, UNICEF and DFID3. The laboratory reports have confirmed that the groundwater in Bangladesh is severely contaminated by arsenic, resulting in a large number of populations suffering from the toxic effects of arsenic contaminated water.

Recent studies in Bangladesh indicate that the groundwater is severely contaminated with arsenic above the maximum permissible limit of drinking water (Table 1).

According to DPHE–BGS–MML (1999), if the samples are collected from deep-tube wells (strainer depth > 150 m), only 1% of samples are exceeding the allowable limits of 0.05 mg/l.

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Figure 1 | Ganges-Deltaic zone in geographical location.

The Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) has been conducting a national screening in Bangladesh. Arsenic in groundwater above the acceptable level of 0.05 mg/l (Bangladesh Standard for Drinking Water) was found in 61 districts and in 433 thanas (Table 2) during the study period.

BAMWSP conducted a survey to identify arsenic contaminated tube-wells in two phases. In the first phase, the survey conducted by BAMWSP included 80,390 tube-wells in 6 thanas, and the number of contaminated tube-wells identified was 38,739 (48.19%). BAMWSP examined 544,975 tube-wells in the second phase (still ongoing) out of which 252,214 (46.28%) tube-well waters have been found to be contaminated with excess arsenic (BAMWSP 2001). The estimate of total population exposed to arsenic contaminated water by the DPHE, BGS and MML in phase I was in the range of 18.5–22.7 million. But in phase II, they furnished two estimates of population exposure based on a project population of 125.5 million in 1999. The total population exposed to arsenic contaminated water above 0.05 mg/l and 0.01 mg/l are estimated, using the Kriging method, to be 32.5 million and 56.7 million, respectively. Based on statistics of thana level the total population exposed to arsenic contaminated water above 0.05 mg/l and 0.01 mg/l are estimated as 28.1 million and 46.4 million, respectively. At present several thousands of people are suffering from arsenic-related diseases and millions are at risk of arsenic poisoning from drinking groundwater with arsenic in excess of the acceptable limit (Rahman *et al.* 2003). Figure 2 represents the As concentration in different partes of Bangladesh. But the total dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified. Thus access to safe drinking water remains an urgent human need in developing countries in general and Bangladesh in particular.

ARSENIC REMOVAL TECHNOLOGIES APPLIED IN BANGLADESH

Several methods of treating water for arsenic reduction are available. The most commonly used methods mostly utilize

Table 1 | Summary report of As contamination in shallow tube-wells in Bangladesh

Period	Survey conducted by	No. of samples (districts)	Remarks
1996	GOB	400	50% of samples are above Bangladesh Standard (0.05 mg/l)
1998	British Geological Survey (BGS)	2022 (41)	35% of samples are above Bangladesh Standard
1997	SOES and DCH	7800 (35)	59% of samples are above Bangladesh Standard
1995–2000	SOES and DCH	2200 (64)	47 districts are affected
1999	BGS, DPHE and Mott MacDonald Ltd. (MML)	3534 (61)	25% of samples are above Bangladesh Standard

Table 2 | Arsenic contamination situation in Bangladesh

Total population (in million) of the country in 1999	125.5
Total area (in sq. km.) of the country	148,393
Total number of districts	64
Total number arsenic affected districts	61
Total number of thanas (during study period)	496
Total number arsenic affected thanas	433
Total number (million) of tube-wells in the country	9.2
As affected shallow tube wells above 0.05 mg/l	27%
As affected shallow tube wells above 0.01 mg/l	46%
As affected deep tube wells above 0.05 mg/l	1%
As affected deep tube wells above 0.01 mg/l	5%
Number of arsenicosis patients reported so far	13,300
Percentage of population exposed to arsenic contamination above 0.05 mg/l	28.1–32.5
Percentage of population exposed to arsenic contamination above 0.01 mg/l	46.4–56.7

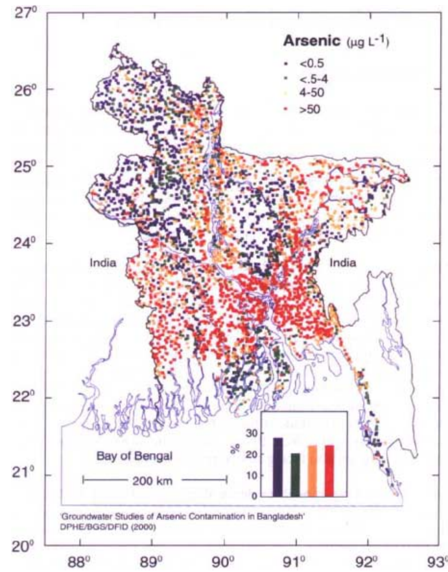

Figure 2 | Arsenic (point source) concentrations in Bangladesh (DPHE & BGS 2000).

principles of oxidation, precipitation/co-precipitation, adsorption onto sorptive media, ion exchange and physical separation by synthetic membranes (Cheng *et al.* 1999; Clifford 1999; Oh *et al.* 2000; Emett & Khoe 2001; Rahman *et al.* 2003). In consideration of lowering the drinking water standards by the United State Environmental Protection Agency (USEPA), a review of arsenic removal technologies was made to consider the economic factors involved in implementing lower drinking water standards for arsenic (Cheng *et al.* 1999).

Although a number of treatment technologies exist that are capable of efficient removal of arsenic from water, the socio-economic conditions that prevail in developing countries in general, and in Bangladesh in particular, do not permit the implementation of most of them on the grounds of the cost involved. In most cases, except in a few cities and towns, there is no centralized water supply system. Individual households or small groups have their own or community tube-wells. Therefore, the solution to the problem of arsenic contamination, in most situations in Bangladesh, demands the development of technology/-technologies that can be implemented at household or small community level at a very low cost. Recently a number of researchers have identified novel processes and/or technologies for arsenic removal that are suitable for use in rural isolated communities. In many cases conventional technologies have been scaled down to suit the rural isolated households and to enable communities to choose safe water for drinking.

Water in around 65% of the areas of Bangladesh contains iron in excess of 2 mg/l, and in many acute iron problem areas, the concentration of iron is as high as 15 mg/l. Therefore, arsenic has been found to co-exist with iron in many situations. The iron precipitates [$Fe(OH)_3$] formed by oxidation of dissolved iron present in groundwater have an affinity for the adsorption of arsenic. In such situations, arsenic can be removed by both co-precipitation and adsorption onto the precipitated ferric hydroxide ($Fe(OH)_3$) after oxidation of this water. The authors collected groundwater naturally contaminated with arsenic and having a very high iron content from an arsenic contaminated area. Samples were shaken during the time of collection and transportation, and allowed to settle in the laboratory. This process removed more than 65% of the arsenic, where raw groundwater arsenic and iron concentrations were in the range of 0.1 mg/l to 0.9 mg/l and 4 mg/l to 15 mg/l, respectively. But the arsenic removal rate is largely controlled by the arsenic concentration, iron concentration, iron/arsenic ratio and pH value (Figures 7, 8 and 9).

Therefore, the use of the presently used iron removal plants that operate on the principle of aerating ferrous iron to convert it into ferric iron for precipitation can be a cost-effective solution for treating both iron and arsenic together in the context of Bangladesh.

This study is aimed at identifying the arsenic contamination problems of groundwater in Bangladesh and then an attempt is made to evaluate the performance of existing arsenic and iron removal plants (AIRPs) in Bangladesh.

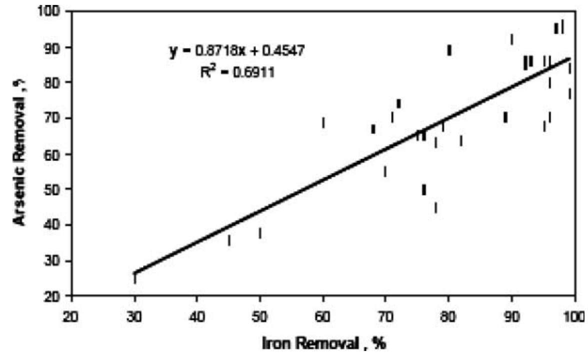

Figure 4 | Correlation between Fe and As removal in treatment plants.

ARSENIC AND IRON REMOVAL PLANTS (AIRPS) IN BANGLADESH

The conventional community type iron removal plants (Figures 3–5) in Bangladesh, constructed on the principles of aeration, sedimentation and filtration in a small unit, have been found to remove arsenic without any added chemicals. The conventional community type IRPs, depending on the operating principles, more or less work as Arsenic Removal Plants (ARPs) as well. A study suggests that As(III) is oxidized to As(V) in the IRPs to facilitate higher efficiency in arsenic removal in IRPs constructed in Noakhali (a district of Bangladesh).

Figure 3 | Typical community AIRP.

Groundwater drawn by hand pump from a tube-well drops into the aeration/ sedimentation chamber (around 1 m diameter and 1 m height, with cascades on top of this chamber for better aeration). This promotes oxidation of iron and arsenic(III) by the air. The aeration/ sedimentation chamber is provided with air vent pipes for better circulation of air (Figure 6). Water from this aeration/ sedimentation chamber passes through the up-flow roughing filtration chamber (around 1 m diameter and 0.8 m height) due to the pressure head from the water level in the aeration/ sedimentation chamber. The water is subsequently collected into a storage tank (around 0.5 m diameter and 0.8 m height) fitted with a water tap for public use. Filtration media comprises brick chips, charcoal and sand. Filtration media is back-washed twice or thrice in a week depending on the rate of discharge through the filter media, and sludge is collected in a holding pond. Back-washing is carried out

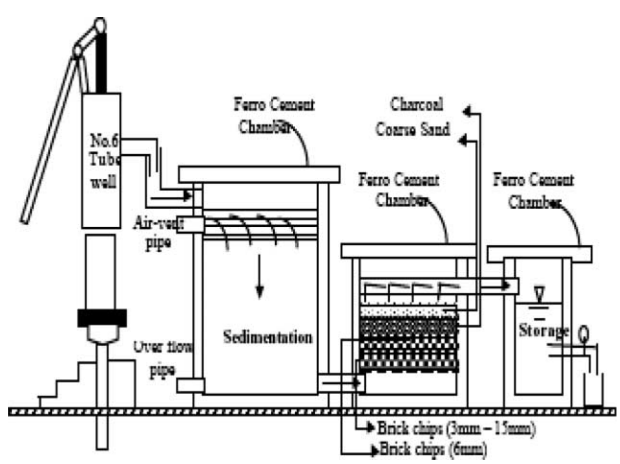

Figure 5 | Flow diagram of community AIRP.

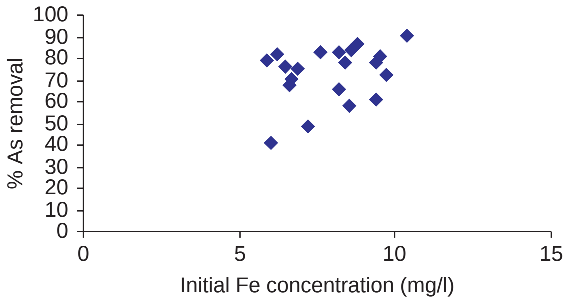

Figure 6 | Correlation between Fe concentration and %As removal.

using the following procedure. First the plant (both sedimentation and filtration chambers) is filled up with water from the tube-well, then drainage valves of both sedimentation and filtration chambers are opened simultaneously to rapidly drain out sludge from both chambers. Then the filtration media is washed with around 25 litres of water by pouring this water from a bucket onto the top of the filter media to remove the impurities within the interstices of the filter media.

The operation and maintenance of this system is very simple. A village level construction, operation and maintenance concept is adopted in all projects. Hence AIRP designs have been chosen such that these are constructed with the locally available construction materials, and villagers can easily operate and maintain the system. A group (at least two persons from the user community are selected as caretakers) are trained during the time of the construction of plants to be responsible for the operation and maintenance of the system. It is also evident from a questionnaire survey of 200 users of these AIRPs (Table 3) that 100% of the AIRP users are willing to use the system. Only 4% of respondents complained about the maintenance of the system; however, 100% of them are willing to pay for this system. This study revealed that these AIRPs are well accepted by the local communities and can be used to remove arsenic if the influent water arsenic concentration is not very high.

No proper methods for the disposal of arsenic contaminated sludge have been developed yet. At present the sludge from the holding ponds of AIRPs is discharged onto cow-dung beds for biochemical reaction. It is apparent from a few experimental studies that the biochemical (e.g. bio-methylation) process significantly reduces the concentration of arsenic in arsenic contaminated sludge when it is mixed with cow-dung. However, further verification is required to better understand this process of transformation of arsenic and the factors affecting this process and to examine whether any pollutant gas will be generated as a by-product.

The average installation costs of a typical AIRP serving around 50 people is around Taka 8000 (US $123), and the annual operation and maintenance cost is around Taka 200 (US$ 3.10).

A field survey was conducted by the authors in which they collected water samples from 60 AIRPs operating in different geo-hydrological conditions in Bangladesh. The Fe–As removal relationship with good correlation in some operating IRPs has been plotted in Figure 4. Results shows that most IRPs can lower the arsenic content of tube-well water up to 50–80% of the original concentrations.

The efficiency of these community type Fe–As removal plants can be increased by increasing the contact time between arsenic species and iron flocs.

Some medium scale Fe–As removal plants of capacities 2000–3000 m^3/d have been constructed for water supplies in district towns based on the same principle. The treatment

Table 3 | Views of users of AIRPs

	Answer (% of users)		
Questions	**Yes**	**Yes, but...**	**No**
Are they satisfied with the service?	96	4	–
Is the system properly maintained?	96	–	4
Are they willing to reimburse the cost of plants?	100	–	–

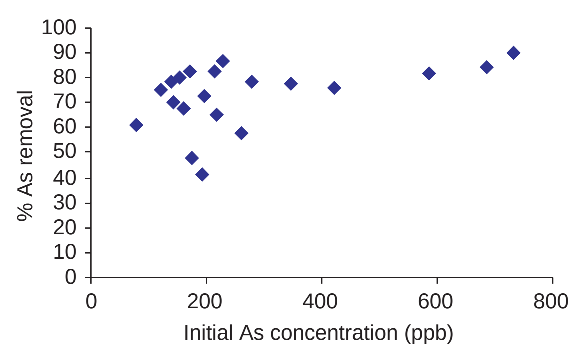

Figure 7 | Correlation between As concentration and %As removal.

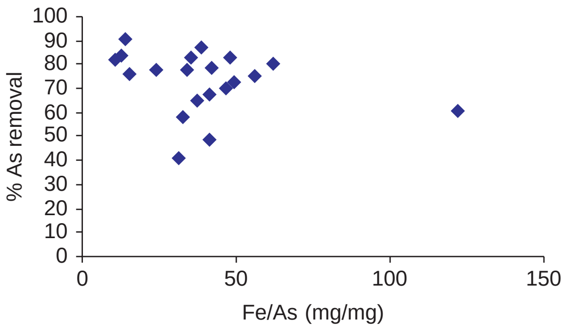

Figure 8 | Correlation between Fe/As and %As removal.

processes involved in these plants include aeration, sedimentation and rapid sand filtration with provision for addition of chemicals, if required. These plants are working well except that the treated water requirement for washing the filter beds is very high.

A field survey was conducted by the authors to evaluate the performance of the AIRPs in small communities and it is apparent from these survey that 16%, 19%, 21%, 20%, 15% and 10% of the plants are operating with arsenic removal efficiencies in the ranges of less than 50%, 50–59%. 60–69%, 70–79%, 80–89% and greater than 90%, respectively, with operating pHs of most of these plants in the range of 6–8.5 and Fe concentrations in the range of 1–10 mg/l.

From this investigation it is apparent that arsenic removal rate in the plants is largely controlled by the arsenic concentration, iron concentration, iron/arsenic ratio and pH value. The test results shown in Figures 6–9 show correlations among iron concentration, concentrations of arsenic, ratio of iron and arsenic and pH with % arsenic removal, respectively. From these results, it is apparent that 70–85% removal of arsenic is possible with Fe concentrations in the range of 6–8 mg/l. and a ratio of Fe to As in the range of less than 60. However, in the case of plants operating at 50–60% arsenic removal efficiency, the influent concentration of arsenic was very low, less than 300 ppb.

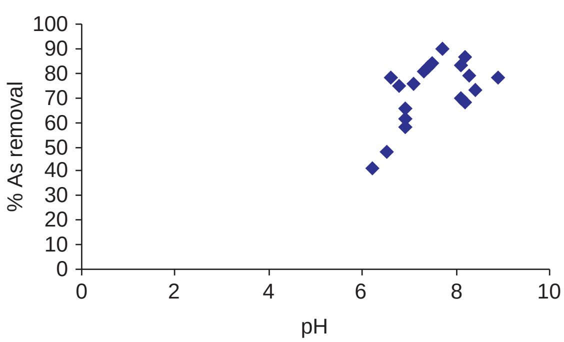

Figure 9 | Correlation between pH and %As removal.

It is also apparent from the field survey that most of the implementing authorities in Bangladesh are promoting these technologies, without proper attention to research and development to renovate and optimize the design to make them more suitable to the local conditions. Water quality parameters generally govern the choice of unit processes of treatment. There is a distinct variation in raw water qualities in different AIRPs, but the same prototype design was used in all cases without proper attention to the variation of water qualities in the areas at the installation site for these selected plants. At present the implementing authorities are reluctant to investigate the cause of failure of the plants of low arsenic removal efficiencies. They have limited research and development capabilities, and there is also limited coordination among the researchers and the implementing authorities. Therefore, there is an urgent need to develop an indigenous technical expertise, together with strong national coordination among different implementing authorities, and research institutions to provide improved design guideline based on raw water quality parameters so AIRPs can be more effective.

It is apparent from this study that most of the AIRPs, operating in Bangladesh, have good arsenic removal efficiencies (Figure 5) for both small isolated communities and densely populated communities where arsenic co-exists with iron at suitable concentrations. and have been performing well and treating water to a certain level. Further research is expected in this arena where arsenic concentration is very high.

DISCUSSION AND CONCLUSION

On a critical analysis of the existing arsenic contamination of groundwater problems in Bangladesh and the results of this study, the following observations and conclusions are made:

- Arsenic contamination in groundwater above 0.05 mg/L was found in 61 districts out of total of 64 districts and in 433 out of the total of 496 thanas in Bangladesh during the period of the study. About 27% of the tested samples collected from shallow tube-wells were found to exceed the concentration of 0.05 mg/L and 46% of the tested samples exceeded the concentration of 0.01 mg/L. In the case of tested water samples collected from deep tube-wells (strainer depth >150 m), only 1% and 5% samples exceeded the contamination level of 0.05 mg/L and 0.01 mg/L, respectively. But the dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified and duly addressed.

- This study revealed that at present operating small community type AIRPs have been performing well in areas where arsenic concentration is not excessively high and these are well accepted by the communities. The system can be easily constructed, operated and maintained by the local community. They have good potential for use in small isolated communities and/or municipalities.
- It is apparent from this study that different implementing authorities in Bangladesh are active in promoting arsenic-removal technologies, without proper attention to research and development to optimize the standard design to make them suitable for the local conditions. Hence, there is an urgent need to develop indigenous technical expertise, together with strong national coordination among different implementing authorities, and research institutions to provide improved design guidelines for good designs and effective use.

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