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Performance of Arsenic and Iron removal plants in Bangladesh

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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. But this dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified. Water in around 65% 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 arsenic can be removed by both co-precipitation and adsorption onto the precipitated Fe(OH)3 in iron removal plants. This study evaluates the performance of 60 arsenic and iron removal plants (AIRPs) presently operating in different geo-hydrological conditions of Bangladesh.

Arsenic contamination of groundwater

Arsenic (As) contamination of groundwater is a major concern in many countries of the world like Argentina, Bangladesh, Canada, Chile, China, England, Ghana, Greece, Hungary, India, Iran, Laos, Mexico, South Africa, Taiwan, Thailand, USA, Vietnam and Zimbabwe. Although the arsenic contamination in groundwater has been reported from various parts of the world, the single largest groundwater contamination so far has occurred in the Bengal delta, mostly in Bangladesh and in a part of West Bengal (India). According to Chakraborti et al (2003) a minimum of 6 million people including about 2 million children belonging to 9 out of the total of 18 districts of West Bengal were drinking arsenic contaminated water, which contains arsenic in excess of 0.05 mg/L. About 40 million inhabitants of these 9 districts are at risk of arsenic toxicity.

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 police stations (thanas, the lowest level of administrative units of the country) (see Table 1) during the study period. The British Geological Society (BGS), Department of Public Health Engineering, Bangladesh, (DPHE) and Mott MacDonald Ltd (MML) conducted the study in two phases and examined 3,534 distributed water samples from 61 districts (except 3 hill districts) in an approximate grid of 6km x 6km (DPHE-BGS-MML, 1999 and BAMWSP, 2001). These include an average of 58 samples per district and 8 samples per thana. 25% of tested samples were found to exceed 0.05 mg/L, the maximum acceptable concentration figure given in the Bangladesh Standard for drinking water, and 42% of the tested samples had concentrations in excess of 0.01 mg/L, the provisional World Health Organization (WHO) guideline value for arsenic in drinking water. This percentage of contaminated tube-wells increases if only shallow tube-wells are considered. In that instance 27% of the tested samples were found to exceed the concentration of 0.05 mg/L and 46% of the tested samples had arsenic concentration of more than 0.01 mg/L. In the case of tested water samples collected from deep-tube-wells (strainer depth > 150m), only 1% and 5% samples exceeded the allowable limits of 0.05 mg/L and 0.01 mg/L respectively.

Table 1. Arsenic Contamination Situation in Bangladesh

Total population (in million) of the country in 1999	125.5
Total area (in sq. km.) of the country	147,570
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

Bangladesh Arsenic Mitigation Water Supply Project (BAMWSP) has been conducting a national screening survey to identify arsenic contaminated tube-wells in two phases mostly in arsenic contaminated areas (BAMWSP, 2001). 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 5,44,975 tube-wells in the second phase (still ongoing) out of which 2,52,214 (46.28%) tube-well waters have been found to be contaminated with excess arsenic. 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 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 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 acceptable limit (Rahman, 2003). But the total dimension of the arsenic occurrence problem in groundwater in Bangladesh is yet to be fully identified. Thus the access to safe drinking water remains an urgent human need in developing countries in general and Bangladesh in particular.

Arsenic removal technologies

Several methods of treating water for arsenic reduction are available. The most commonly used methods mostly utilized principles of oxidation, precipitation/co-precipitation, adsorption onto sorptive media, ion exchange and physical separation by synthetic membranes (Cheng et al, 1999; Cliford, 1999; Emett and Khoe, 2001; Oh et al, 2000 and Rahman, 2003). In consideration of lowering drinking water standards by 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 (Chen 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% 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-exists with iron in many situations. In such situations, arsenic can be removed by both co-precipitation and adsorption onto the precipitated Ferric hydroxide ($Fe(OH)3$) by oxidation of this water. The authors collected arsenic groundwater naturally contaminated with arsenic and having 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 arsenic removal rate is largely controlled by the arsenic concentration, iron/arsenic ratio and pH value. Therefore, the use of the presently used iron removal plants that operate on the principle of aerating ferrous iron to convert them to 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 performance of existing arsenic and iron removal plants (AIRPs) in Bangladesh.

Arsenic and Iron removal plants (AIRPs)

The conventional community type iron removal plants (Figs. 1 and 2) operate on the principles of aeration of ferrous iron to convert it to ferric iron which co-precipitates with arsenic. Groundwater drawn by hand pump from a tube-well drops into the aeration/ sedimentation chamber (around 1m diameter and 1m height, with cascades on top of this chamber for better aeration). This promotes oxidation of iron and arsenic by the air. The aeration/ sedimentation chamber is provided with air vent pipes for better circulation of air (Fig.1). Water from this aeration/sedimentation chamber passes through the up-flow roughing filtration chamber (around 1m diameter and 0.8m 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 0.5m diameter and 0.8m height) fitted with water tap for public uses. Filtration media comprises brick chips, charcoal and sands. 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 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 filter media to remove the impurities within the interstices of the filter media. The operation and maintenance of this system is very simple. 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 operation and maintenance of the system. No proper methods for the disposal of arsenic contaminated sludge have been developed yet. Presently 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 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.

The average installation costs of a typical AIRP serving around 50 people is around Taka 8000 (US $ 134), and the annual operation and maintenance cost is around Taka 200 (US $ 3.33).

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 iron removal efficiencies of 54 plants (90% of the total plants) are more than 90% with values as high as 99%. The remaining 6 plants (10% of the total) are operating with iron removal efficiency of more than 80%. Arsenic removal efficiencies of the AIRPs in small communities are shown in Tables 2 and 3. It is apparent from these results that 17 %, 21%, 44% and 18% of the plants are operating with arsenic removal efficiencies in the ranges of 80-90%, 70—79%, 60-69% and 50-59% respectively. The operating pHs of the most of these plants are in the range of 6 – 8.5. The test results shown in Tables 2 and 3 do not show any correlation among concentrations of arsenic, and the ratio of iron and arsenic. However, in case of plants operating at 50 – 60% arsenic removal efficiency, the influent concentration of arsenic was very low, less than 0.077 mg/L except one plant, where the arsenic concentration was 0.408 mg/L. The installation, operation and maintenance of the system mostly control these variations. It is evident from the field survey that the degree of aeration also influences the degree of treatment.

A village level construction, operation and maintenance concept is adopted in all projects. And 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. It is also evident from a questionnaire survey of 200 users of these AIRPs (as shown in Table 4) 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.

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. It is apparent from Tables 2 and 3 that there is a distinct variations in raw water qualities in different AIRPs, but the same prototype design was used in all cases without proper attention to variation of water qualities in the areas at the installation site for these selected plants. Presently 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,

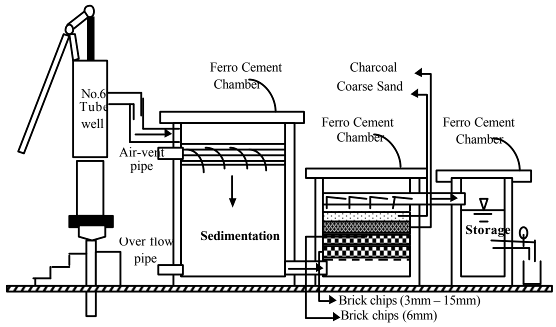

Figure 1. Flow Diagram of Community AIRP

Figure 2. Typical Community AIRP

Table 2. As removal Efficiencies in AIRP

Fe Conc., mg/L	Percentage of sample showing % removal of arsenic in the range of			
	50-59	60-69	70-79	80-90
Less than 1	5	-	-	-
1-3	10	23	3	-
3-6	3	13	3	-
6-9	-	5	10	14
More than 9	-	3	5	3
Total	18	44	21	17

Table 3. As removal Efficiencies in AIRP

Iron/ arsenic ratio	Percentage of sample showing % removal of arsenic in the range of			
	50-59	60-69	70-79	80-90
Less than 5	-	3	-	-
5-10	5	3	-	3
10-20	8	8	6	7
20-35	-	15	10	7
More than 35	5	15	5	-
Total	18	44	21	17

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 for so AIRPs can be more effective.

It is apparent from this study that most of the AIRPs, operating in Bangladesh, have good arsenic and iron removal efficiencies (Tables 2 and 3) and have been performing well and treating water to the satisfactory level except in those areas, where arsenic concentrations are very high. It is evident from field survey that these AIRPs are well accepted by the community. Thus these arsenic and iron removal plants have good potentials for both small isolated communities and densely populated communities where arsenic co-exists with iron at suitable concentrations.

Table 4. Views of Users of AIRPs

Questions	Answer, % of users		
	yes	yes, but..	no
Are they satisfied with the service?	96	4	-
Is the system properly maintained?	96	-	4
Are willing to reimburse the cost of Plants	100	-	-

Conclusion

On a critical analysis of the existing arsenic contamination 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 64 districts and 433 out of the total 496 thanas in Bangladesh during the of study. About 27% of the tested samples collected from sallow 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 case of tested water samples collected from deep-tube-wells (strainer depth > 150m), only 1% and 5% samples exceeded the contamination 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 presently 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 the arsenic-removal technologies, without proper attention to research and development to optimize the standard design to make them suitable for the local condition. 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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