

Arsenic Mitigation Processes on Trial and Tested in Barak Valley, Assam, India.

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Abstract:

Some of the environmental friendly mitigation processes of iron which was evolved and developed domestically also applied and tested for the removal of arsenic, which is an extremely toxic contaminant even in very low concentrations. Based on the combined use of co-precipitation, adsorption, on the principle of aeration (oxidation) of Fe^{2+} to Fe^{3+} and sedimentation technique for removal of arsenic (As) from drinking water has been evaluated in water from seven wells in Barak Valley, Southern Assam, India. Field data revealed that As concentrations may, by these methods, be reduced up to 67% to 99% depending on the methods used. The presence of small amounts of ferric salt in water greatly facilitated sedimentation of the precipitate. Adsorption of inorganic contaminants, which helps precipitation of metal hydroxide solids, was likely to be the dominant mechanism of As removal. Arsenic in groundwater of some pockets of Barak Valley, Assam, is present in excess of the safe limit set for India ($<50 \mu g l^{-1}$) while some areas are within the range of the limit set by BIS ($10-50 \mu g l^{-1}$). The present study is carried out from 2007-2010 on underground drinking water quality at Barak Valley, Assam, India.

Keywords: mitigation processes, toxic contaminant & co-precipitation and adsorption

Introduction

Arsenic contamination is a serious threat for human health and its incidence in the environment has been largely reviewed by the literature (Mandal and Suzuki, 2002; Smedley and Kinnburg, 2005). Arsenic is an abundant trace element and it exists in both inorganic and organic forms in water. It is present in the environment mainly in two oxidation states, arsenate and arsenite, the latter considered to be more toxic (Farquhar et al, 2002; Goldberg and Johnston, 2001).

1.1 Drinking water status

Until 1990s most rural people obtained and consumed water from the hand-dug wells, ponds, rivers or canals. These waters were usually consumed directly without any treatment. So epidemics of diarrhea and other water-borne diseases were very common. Hundreds of people particularly the infants died only because of drinking these unsafe waters. The idea of tapping

groundwater, which seemed to be clean, plentiful and pathogen-free under anaerobic condition, was accepted and hand tube wells were considered reliable means for extracting groundwater at an affordable cost. Approximately 90 percent of the rural population of Barak Valley, Assam get their drinking water from tube wells that have been sunk over the last 20 years.

1.2 Arsenic in drinking water

Arsenic contamination in water is a worldwide problem. Arsenic has been detected in several districts of Assam, Arunachal Pradesh, Tripura, Manipur, and Nagaland (Singh, 2004). Further UNICEF and the Public Health Engineering Department, Govt. of Assam, reported the presence of arsenic in the groundwater of Karimganj district, following reports of extensive contamination of groundwater by Arsenic in West Bengal, India & the western part of Bangladesh.

Arsenic mobilization occurs under natural conditions as a result of volcanic emissions, weathering reactions and biological activity. However, anthropogenic factors may have also contributed to magnify the problem (Mohan and Pittman, 2007).

1.3 Source of arsenic

Arsenic in groundwater mainly results from minerals dissolving from weathered rocks and soils (2-5%) (Mandal and Suzuki, 2002). However, human activities, such as the use of arsenical preservatives in the wood industry and arsenical pesticides in agriculture, have also elevated Arsenic concentrations in groundwater in recent years (Chakraborti *et al.*, 2002; Matschullat, 2000). Arsenic pollution in groundwater has become a major public concern in many countries and potentially impacts millions of people, since more and more groundwater withdrawal is taking place due to human usage and agricultural irrigation (Smith *et al.*, 1998). In Silchar Block of Cachar District, the groundwater arsenic concentration is generally low, but some samples surpass the current BIS limit of $50 \mu\text{g l}^{-1}$. Several treatment technologies, such as co-precipitation, adsorption, ion exchange, and membrane process have been demonstrated to be effective in removing Arsenic from contaminated groundwater (Cheremisinoff, 1998).

MATERIALS AND METHODS

Total arsenic content was estimated by highly sensitive Flow Injection Hydride Generation Atomic Absorption Spectrophotometer (FI-HG-AAS). A Perkin-Elmer Model 3100 AAS equipped with a Hewlett-Packard Vectra computer with GEM software, Perkin-Elmer EDL System 2, arsenic lamp (lamp current 400 mA) and Varian AAS Model Spectra AA-20 with hollow cathode As lamp (lamp current 10 mA) were used at School of Environmental Studies, Jadavpur Universities (SOES-JU), Kolkata. Shimadzu (Japan) double beam spectrophotometer (Model UV-150-02) and Phenanthroline method at 510 nm is used for iron analysis. The details of the instrument are available in the literature (IMS 1990).

2.1 Sample collection and preservation

Hand tube well water samples are collected in pre-washed (with 1:1 HNO_3) polyethylene bottles after pumping off at least for 5 minutes. After collection, concentrated HNO_3 (1.0ml per liter) is added as preservative (Chatterjee *et al.*, 1993). Samples are then taken to laboratories for further analysis.

2.2 Iron and Arsenic Removal Technologies being Tried and Tested in Barak Valley

Several technologies currently are being used by the villagers and urban dwellers for removal of iron. These technologies claim to be effective in removing iron as well as arsenic from tube wells water. These are all new

and in development stage. The effectiveness, viability and sustainability of the technologies under field conditions in Barak Valley, Assam are yet to be ascertained before their adoption and scale-up thereof. Some of the technologies so far tried at field level are discussed below.

Seven major Household Water Treatment Systems (HWTS) were found to be in use in different parts of Barak Valley for removing excess iron from groundwater. These systems with or without appropriate modification could also remove or reduce arsenic. These are based on the following principles:

1. **Bucket Treatment Unit:** Involves the principle of oxidation by the way of simple aeration and coagulation.
2. **Container Treatment Unit:** Utilizes gravel-sand filtration method in a simplified version of Pitcher Treatment Unit.
3. **Passive Sedimentation:** Co-precipitation with $\text{Fe}(\text{OH})_3$ particle generated by the oxidation of Fe^{II} to Fe^{III} present in ground water and sorption on $\text{Fe}(\text{OH})_3$ provided by additional rust particles [$\text{Fe}(\text{OH})_3$ and Fe_2O_3] introduced into the system by extra iron filings.
4. **Arsenic and Iron Removal Plant (AIRP):** Adsorption onto sorptive media of gravel/chips and sand particles. Addition of rusted iron filings can improve arsenic removal efficiency.
5. **Improved AIRP:** Horizontal Kinetics through coarse sand, gravel/chips and charcoal. Addition of rusted iron filings can improve arsenic removal efficiency.
6. **Ion exchange:** In this method, a column of ion-exchange resin is added to the AIRP system.
7. **SORAS method:** Photochemical oxidation of As(III) followed by precipitation or filtration of As(V) adsorbed on Fe(III) oxides.

2.3 Method 1- Bucket Treatment Unit(Auto-attenuation)

This simple and low-cost method is used extensively by the poorer sections of the community. It uses a bucket of 20-litre capacity and an ordinary wooden stick (**Fig.1**). The water containing dissolved iron in high concentration (and having low level of arsenic) is poured into the bucket. Powdered alum is taken in a piece of cloth and dipped into the water and swirled for 10-15 seconds followed by stirring. The water is allowed to stand for about 12 hours for settling. During this process, dissolved iron is readily oxidized and forms ferric precipitates. The air-oxidation of Fe^{2+} to Fe^{3+} generates favorable substrate with surface reactive sites for the adsorption of As(III) as well as As(V) species. The supernatant is decanted and consumed as drinking water. Average arsenic concentration of $36 \mu\text{g l}^{-1}$ was reduced

to $<3 \mu\text{g l}^{-1}$ (BDL). As the foul smell of iron is removed, people find it to be a cost-effective and simple method for mitigation of iron problem. Along with iron, total arsenic was also attenuated to the extent of 90-95 % (**Table 1**). This unit is available in villages of Karimganj district and peripheral area of Silchar Block. The test results showed that it needs further modifications for higher arsenic concentration in groundwater.

2.4. Method 2- Container Treatment Unit

This is nothing but a simplified version of the traditional Pitcher Treatment Plant used at household levels for rendering water microbiologically safe. The same principle is utilized for removal of iron (and arsenic). Contaminated water is passed through a vertically stacked series of pitchers containing different filter media such as gravel-sand mixture, charcoal-sand mixture and coarse sand, etc. The filtered water is collected in the lowermost pitcher.

In Barak Valley, a simplified version of the pitcher plant unit is used for removal of iron. Instead of a vertical series of pitchers, the unit is constructed in a single 20 litre capacity tin container (most commonly empty mustard oil metallic container) filled with three successive layers of filtration media. The uppermost layer is coarse sand, followed by a middle layer of gravel, with the lowermost layer made of charcoal (**Fig. 2a and Fig. 2b**). The filtered water comes out through an opening at the bottom and is collected in a container. The filtration media, which gets impregnated with reddish-brown iron deposits, is washed once in a month in a pit with a basket made of bamboo slats and reused.



Fig.1. Bucket treatment Unit



Fig. 2(a)



Fig. 2(b)

Fig. 2.(a) Front View and (b) Top Layer of Container Treatment Unit

This method is used by a number of households in the Meherpur area of Silchar-South, Barak Valley, Assam for removal of iron. Average arsenic concentration of $20 \mu\text{g l}^{-1}$ found in the groundwater of this area was reduced to $<5 \mu\text{g l}^{-1}$ after filtration (**Table 1**).

2.5. Method 3- Passive Sedimentation

Iron is also removed from groundwater by passive sedimentation in which the water is pumped out and stored at least for a period of 24 hours during which the iron is precipitated as $\text{Fe}(\text{OH})_3$ after natural oxidation. As groundwater in large parts of Ganga-Meghna-Brahmaputra (GMB) Basin in India and Bangladesh has high iron concentration ($1-2 \text{ mg l}^{-1}$ or even more), the passive sedimentation method can be utilized for removing arsenic by both co-precipitation and adsorption onto the precipitated $\text{Fe}(\text{OH})_3$. If this method is coupled with a filter bed comprising a layer of gravel and iron filings along with aeration, the arsenic removal efficiency is improved. In a household at Bhola Giri Road, Silchar-South, arsenic concentration was found to be reduced from $78 \mu\text{g l}^{-1}$ to $<3 \mu\text{g l}^{-1}$ (**Table 1**) after using such a sedimentation unit (**Fig. 3a and Fig. 3b**).

2.6. Method 4- Arsenic and Iron Removal Plant I (AIRP I)

The conventional small-community/household iron removal plant operates on the principle of aeration (oxidation) of Fe^{2+} to Fe^{3+} and sedimentation. Groundwater drawn by pump from tube-well is dropped into a storage chamber where aeration takes place. Water then percolates through a filtration chamber comprising gravel, coarse sand and charcoal beds. This method can be used to co-precipitate oxidized arsenic through adsorption to the reactive sites of $\text{Fe}(\text{OH})_3$ and subsequent sedimentation by gravity force. Arsenic removal efficiency was increased when the groundwater dropped through a perforated iron pipe into the storage chamber due to higher aeration time for oxidation. Furthermore, the filtration chamber contains a bed of rusted iron filings [$\text{Fe}(\text{OH})_3$ and Fe_2O_3] in addition to gravel, coarse sand and charcoal (**Fig. 4a, Fig. 4b and Fig. 4c**). The iron filings further enhance the co-

precipitation of arsenic with iron bed. Filter bed materials are washed quarterly and the run off sludge is let out through a drain to a pit. The sand layer is ideally replenished every four months or so. This method is cost effective and materials are easily available. Arsenic removal efficiency is found to be around 97% with its concentration going down from $43 \mu\text{g l}^{-1}$ to $<3 \mu\text{g l}^{-1}$ (Table 1). This type of filter is available in the South-Silchar, Cachar District.

Method 5- Arsenic and Iron Removal Plant II (AIRP II)

The groundwater from a deep tube-well (>50m depth) was sprayed like a fountain to provide maximum aeration time and collected over a circular disc and subsequently fall through a three co-circular platforms with increasing diameter to give a cascading effect. The lowermost platform also has a layer of pebbles to give a rough surface for increased turbulence. From here, water enters the first chamber of the filtration unit, then passes to the central chamber through a perforated iron pipe from where it traverses through four/five horizontal compartments filled with coarse sand, gravel, rusted iron filings and charcoal, respectively shown in (Fig. 5a, Fig. 5b, Fig. 5c and Fig. 5d). The arsenic removal efficiency is found to be around 97% where arsenic is brought down from $24 \mu\text{g l}^{-1}$ to $<3 \mu\text{g l}^{-1}$ (Table 1). Filter bed materials washed once in every four months and occasional replacements of materials are done. The plant unit is covered with a net to avoid contamination from outside. This kind of plant units have been in use in multistoried building of Silchar town of Cachar District and in Karimganj town of Barak Valley, Assam.

Method 6- Ion Exchange Resin Method

This method involves an ion exchange resin (cationic) apart from aeration and filtration units. The underground water is first passed through the cascade of systems namely aeration with fountain, coarse sand, gravel and charcoal. The purified water is then passed through a tank partly filled with the granules of a resin X which absorbs positive ions and then collected in an under ground reservoir. Finally it is lifted to an over head tank for distribution. The cationic ion-exchanger (resin X) is pre-treated with sodium chloride (NaCl) solution, which creates an abundance of chloride ions on the reactive sites. When feed water with arsenic enters the resin bed, the chloride ions are exchanged for the arsenic ions. The exhausted resin bed is regenerated by passing concentrated sodium chloride solution through the column in the opposite flow direction. However, if the effluent water has high sulphate concentration, then the sulphate ions are exchanged with the reactive sites of the cation exchanger in preference to arsenic. Hence, the effectiveness of the ion exchanger depends on the relative affinity of the resin for arsenic and low concentration of sulphate ion in groundwater.

The arsenic removal efficiency of this method is up to 97% and can lower the concentration from $25 \mu\text{g l}^{-1}$ to $<3 \mu\text{g l}^{-1}$ (Table 2). The materials used are cleaned with back wash after three months to regenerate its efficacy.

Method 7- SORAS method

SORAS is a simple method that uses irradiation of water with sunlight in PET or other UV transparent bottles to reduce arsenic level from drinking water (Wegelin et al., 2000). The process is developed by Swiss Federal Institute of Environmental Science and Technology, Switzerland and Swiss Agency for Development and Cooperation (SDC), Bangladesh. The method is based on photochemical oxidation of As (III) followed by precipitation or filtration of As (V) adsorbed on Fe (III) oxides. Field tests in study sites showed removal efficiency between 45-78% with an average of 67%. Concerning the Indian guideline value of $50 \mu\text{g/l}$, SORAS can treat raw water having an arsenic concentration below 100 – 150 $\mu\text{g/l}$. This method is being used by people throughout the South Assam.



3a: (Front view)



3b: (Top layer)

Fig.3. Passive Sedimentation Unit

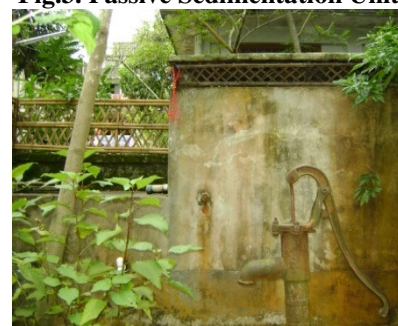


Fig. 4a (Front view)09

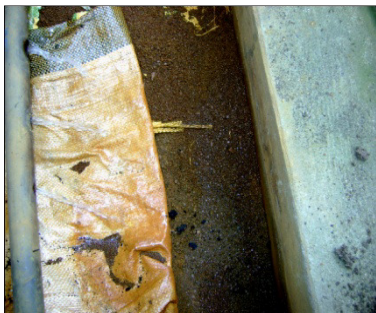


Fig. 4b(Aeration and Sand layer)



Fig. 4c (Coarse Sand)

Fig. 4. Arsenic and Iron Removal Plant I (AIRP I)



Fig. 5a (Front view)



Fig. 5b (Aeration-Fountain)

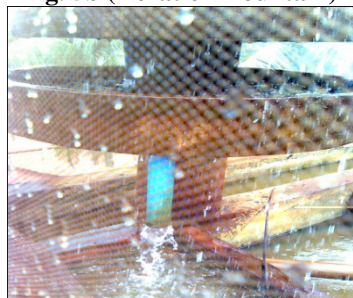


Fig. 5c (Mouth of first unit)



Fig. 5d (Horizontal view)

Fig. 5. Improved AIRP II

Discussion

The present study on a four-year average during 2007-2010, reveals that high iron concentrations are also the characteristic feature of most groundwater sources in this area and many groundwater consumers have adopted measures for removal or reduction of iron from groundwater. It would, therefore, be most appropriate to further adapt these iron-removal technologies to remove or reduce arsenic as well, as this would have better acceptability among the consumers.

A total of seven methods for iron removal were examined and tested wherever appropriate or necessary, the owners were motivated to modify these techniques to achieve better results for arsenic removal. Most of these methods or their variants were also in use in Bangladesh for removal of iron and arsenic. For instance, the simplest technique of “**bucket treatment**” was also found to achieve 90-95 % reduction provided the arsenic concentration of water did not exceed $70-80 \mu\text{g l}^{-1}$. In Bangladesh, this method was found to have an efficiency of 67-83 %, which could be improved to 94 % after BUET (Bangladesh University of Engineering & Technology) adopted certain modifications such as addition of ferric chloride and potassium permanganate (Rahman *et al.*, 2003). Cheng *et al.* (1994) reported 99% removal of arsenic in laboratory by coagulation process under optimal conditions. Other workers (Edwards, 1994; Kartinen and Martin, 1995) have also worked on flocculation method at variable pH ranges and found its arsenic removal efficiency to be around 95%.

The arsenic removal efficiency of the **pitcher treatment unit** has been found to be in the range of 59-95 %, although it depends on the maintenance of the system and the quality of water. Assessments made by different international agencies in Bangladesh showed that this technology was effective in removing arsenic, but the system may be quickly clogged if ground water contains excessive iron (Rahman *et al.*, 2003). Moreover, if the batches are left for too long, dissolved iron concentrations reach unacceptable levels (Ramaswami *et al.*, 2000).

The other treatment methods employing **mechanized**

Table-1. Reduction of Arsenic concentration in groundwater after treatment in different study sites

Experimental Methods	Annual mean value of Arsenic concentration (2007-2010) before filtration ($\mu\text{g l}^{-1}$)	Mean Arsenic concentration after filtration ($\mu\text{g l}^{-1}$)
Method 1	39	<3(BDL)
Method 2	24	<5
Method 3	69	<3
Method 4	39	<3
Method 5	24	<3
Method 6	28	<3
Method 7	65	<20

aeration, oxidation and filtration at various degrees of sophistication could be useful for apartment dwellers in cities like Silchar, where increasing numbers of households are living in multi-storey apartments and are exploiting groundwater either as a primary or supplementary water source. Most of the **AIRP plants** in Bangladesh were found to remove arsenic efficiently in the range of 84-99 % and could be useful for isolated communities as well as densely populated communities where arsenic and iron co-exist in suitable proportions. The **ion exchange resins** were also found to perform at satisfactory levels (Rahman *et al.*, 2003).

Thus a range of options could be exploited for mitigating the problem of arsenic contamination in the study area. In those sites where arsenic concentration exceeds $100 \mu\text{g l}^{-1}$, reverting to surface water sources could constitute the best option. However, in areas having less than $100 \mu\text{g l}^{-1}$, an appropriate and acceptable arsenic-iron removal technology could perhaps provide a viable mitigation option.

CONCLUSIONS

To save millions of people from arsenic poisoning it is important to detect the arsenic concentration in groundwater and also to provide a suitable, user friendly and cost effective arsenic removal process for the rural people of Barak Valley, South Assam. On the other hand removal technologies so far tried for the rural people have potential but not tested thoroughly for adoption.

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BDL-Below detection limit

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MCL - Maximum contaminant level

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