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Performance Evaluation of Technologies Currently Applied in Bangladesh for Arsenic Removal in Presence of Competitive ions

Nadim R. Khandaker[1] and Tom Murphy

Abstract. This paper discusses the performance of arsenic removal filters in different regional groundwaters of Bangladesh. Bangladesh is a country where a public health crisis is occurring due to the contamination of groundwater with arsenic. It is estimated that over 70 million people are consume arsenic contaminated groundwater. Arsenic filters are being interjected as a means of arsenic mitigation to provide safe water. This paper reports on the performances of some of the filters deployed in Bangladesh with respect to source water quality. The evaluation program reported in the paper showed that the performance (efficiency and the volume of water a filter can treat) of the filters are dependent on the quality of the groundwater, mainly the pH of the water, presence of competitive ions such as phosphates and silicates. The performance of the same filter make varies from region to region, based on the ground water matrix.

NWRI RESEARCH SUMMARY

Plain language title

Performance Evaluation of Technologies Currently Applied in Bangladesh for Arsenic Removal in Presence of Competitive ions

What is the problem and what do sicentists already know about it?

Arsenic in the groundwater of Bangladesh is currently poisoning up to 70,000,000 people. Once people are sick, there is little ability to reverse most of the damage. As well as the general impairment of productivity, thousands develop cancers, gangrene with limb amputation and death. The only effective management is prevention. Removal of arsenic from water can be compromised by other anions such as phosphate and silicate that can interfere with arsenic treatment process.

Why did NWRI do this study?
Arsenic poisoning is a global problem and areas in Canada also suffer from arsenic contamination. Several agencies have requested NWRI's support with arsenic management. Currently our collaboration is facilitating the exchange of arsenic management gained in Bangladesh to other countries with similar problems, such as Cambodia.

What were the results?
Arsenic treatment filters can provide safe drinking water. The performance depends upon the quality of the groundwater, especially its pH, and the presence of phosphate and silicate

How will these results be used?
Currently a variety of water management procedures are still being evaluated for arsenic management. The principles of this research apply to several treatment methods. Likely different management approaches will be required in various regions.

Who were our main partners in the study?
Bangladesh Center for Scientific and Industrial Research.

Évaluation de la performance de techniques utilisées au Bangladesh pour éliminer l'arsenic en présence d'ions compétiteurs

Nadim R. Khandaker[2] et Tom Murphy

Résumé. Le présent article traite de la performance de filtres utilisés pour éliminer l'arsenic de l'eau dans différentes régions du Bangladesh. Le Bangladesh est confronté à une crise de santé publique due à la contamination de l'eau souterraine par l'arsenic. On estime que plus de 70 millions de personnes consomment l'eau souterraine contaminée par l'arsenic dans ce pays. Les filtres sont utilisés pour obtenir de l'eau potable exempte d'arsenic. Cet article rend compte de l'efficacité de certains des filtres utilisés au Bangladesh. Le programme d'évaluation présenté dans l'article a montré que la performance des filtres (efficacité et volume d'eau traitée) est tributaire des propriétés de l'eau souterraine, surtout du pH et de la présence d'ions compétiteurs comme les phosphates et les silicates. La performance d'une même marque de filtre varie d'une région à l'autre selon la matrice (eau souterraine).

Sommaire des recherches de l'INRE

Titre en langage clair
Évaluation de la performance de techniques utilisées au Bangladesh pour éliminer l'arsenic en présence d'ions compétiteurs

Quel est le problème et que savent les chercheurs à ce sujet?
Au Bangladesh, 70 millions de personnes sont intoxiquées par l'arsenic présent dans l'eau souterraine. Une fois que la maladie s'est installée, elle est à peu près irréversible. Outre la perte de productivité, l'intoxication à l'arsenic provoque des milliers de cancers, la gangrène avec l'amputation d'un membre, et la mort. La prévention est la seule solution. D'autres anions, comme le phosphate et le silicate, peuvent compromettre l'élimination de l'arsenic présent dans l'eau en interférant avec le traitement.

Pourquoi l'INRE a-t-il effectué cette étude?
L'intoxication à l'arsenic est un problème mondial; la contamination par l'arsenic touche également des régions canadiennes. Plusieurs organismes ont demandé l'aide de l'INRE.

Cette collaboration permet d'étendre les connaissances acquises au Bangladesh à des pays qui ont des problèmes similaires, comme le Cambodge.

Quels sont les résultats?
Les filtres à arsenic sont utilisés pour obtenir de l'eau potable. La performance de ces filtres dépend des propriétés de l'eau souterraine, particulièrement du pH ainsi que de la présence de phosphate et de silicate.

Comment ces résultats seront-ils utilisés?
Diverses méthodes de gestion des eaux sont actuellement évaluées pour ce qui est de l'élimination de l'arsenic. Les principes de cette recherche sont valables pour plusieurs méthodes de traitement des eaux. Les approches adoptées varieront probablement selon les régions.

Quels étaient nos principaux partenaires dans cette étude?
Center for Scientific and Industrial Research du Bangladesh

Performance Evaluation of Technologies Currently Applied in Bangladesh for Arsenic Removal in Presence of Competitive ions

Nadim R. Khandaker[1] and Tom Murphy[2]

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Abstract. This paper discusses the performance of arsenic removal filters in different regional groundwaters of Bangladesh. Bangladesh is a country where a public health crisis is occurring due to the contamination of groundwater with arsenic. It is estimated that over 70 million people are consuming arsenic contaminated groundwater. Arsenic filters are being interjected as a means of arsenic mitigation to provide safe water. This paper reports on the performances of some of the filters deployed in Bangladesh with respect to source water quality. The evaluation program reported in the paper showed that the performance (efficiency and the volume of water a filter can treat) of the filters are dependent on the quality of the groundwater, mainly the pH of the water, presence of competitive ions such as phosphates and silicates. The performance of the same filter make varies from region to region, based on the ground water matrix.

Keywords: Arsenic, Bangladesh, Arsenic removal filter performance, groundwater quality

1. Introduction

Epidemiological studies carried out over the past three decades have established the link between adverse health effects and the presence of arsenic in drinking water. The health effects of ingested inorganic arsenic include skin and internal cancers and non cancer-related effects on skin, vascular and gastrointestinal systems. Aquifers in Bengal basin encompassing parts of West Bengal, India and Bangladesh, Taiwan, northern China, Hungary, Mexico, Chile, Argentina and many parts of the USA have arsenic at concentrations in excess of regulatory limits (Khandaker, et al., 2003). Many water treatment systems have limited capabilities-typically only chlorination-therefore, additional efforts to remove arsenic will substantially increase the cost of treated water. Clearly there is an urgent need to find either cost effective arsenic removal systems or enhance the performance of existing systems in order to limit the financial burden on the affected communities. This is more a concern in the context of Bangladesh, a country where over 70 million people are consuming arsenic contaminated water (Khandaker and Brady, 2002).

The objective of this paper is to report on a research program carried out to evaluate the performance of small scale arsenic removal systems applied in the arsenic affected area's of Bangladesh. The technologies applied

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are generally based on adsorption principles, and the base media generally consist of ferric coated activated alumina, granular ferric hydroxide, iron filings, and anion ion-exchange resins. The performance evaluation was done on actual well waters at five different locations to observe the performance of the media under the influences of existing pH and competitive ions.

2. Description of the more prominent arsenic filters being used in Bangladesh

The arsenic removal filters that are being used in Bangladesh can be categorized into two sizes, household units that serve the cooking and drinking requirements of a single family and small community unit that serve the cooking and drinking needs of ten or more families. Typical household (a family of 5 persons) demand for water for the purpose of cooking and drinking is between 35 to 45 liters per day.

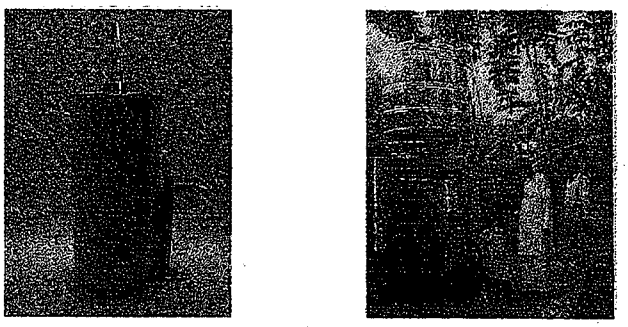

Figure 1. Pictures of a typical household size arsenic removal filter and small community size filter.

The five more prominent filters evaluated by the Bangladesh Council of Scientific and Industrial research (BCSIR) can be classified by the size of the unit and the mechanism of arsenic removal as fellows:

1. *MAGC/ALCAN arsenic removal filter for household use*: The MAGC/ALCAN household filter consists of two plastic buckets placed in series on top of each other containing ferric-coated activated alumina media (AASF50). The water poured into the system flows downward through the filter media. It is designed to serve a single household. The arsenic in the raw water is removed by adsorption onto the AASF50 media.

2. *READ-F*: The Read-F filter consists of a prefabricated plastic shell containing a metal oxide proprietary media designed to remover arsenic. The filter is a pour through household level filter with water flowing downwards through the filter bed. The Read-F filter has a layer of sand on top of the media bed to remove turbidity and iron fouling. The process of arsenic removal by the filter is by adsorption.

3. *SONO 45-25*: The SONO filter is an indigenous filter based on the use of zero valent iron as the active ingredient for arsenic removal. The filter consists of two plastic buckets in series placed on top of each other. The top bucket contains a top layer of sand followed by a layer of iron filing, and a bottom layer of sand. The

bottom bucket consists of layers of sand and charcoal. The top sand layer in the top bucket serves as a pre-filter to remove turbidity and iron fouling. The iron-filing layer serves as the source for the active ingredient metal hydroxide, which removes arsenic by the process of precipitation, co-precipitation, and adsorption. The subsequent sand and charcoal layers remove the arsenic rich solid iron hydroxide by filtration.

4. *TETRATREAT*: This system is designed to serve the needs of ten families for their drinking and cooking needs. The active ingredient in the TETRATREAT arsenic removal filter is an anion exchange resin. Before filtration by the ion exchange media an oxidant is added to the source water and passed through gravel filled contact chamber where oxidation of the arsenic (III) to the charged form of arsenic (V) occurs. After the contact chamber the water passes by gravity through a bed of anion exchange resin that removes the negatively charged arsenic (V) species in the water by ion exchange.

5. *SIDKO*: The SIDKO arsenic removal system is a small community based system designed to serve ten or more families. Granular ferric hydroxide (GFH) is used as the active ingredient for arsenic removal. The system consist of a sand pre-filter bed which remove turbidity and iron fouling, followed by the bed of GFH which is the active ingredient that removes arsenic by adsorption.

3. Groundwater quality parameters of concern with respect to arsenic removal filter operation in Bangladesh

The quality of groundwater varies in Bangladesh based on the geology associated with the aquifer and also the depth from which the well water is withdrawn. Table 1 is a summary of data known to affect the performance of arsenic removal systems, showing the variation of water quality parameters from five regions of Bangladesh where the five arsenic removal systems described in Section 2 were evaluated.

Table 1. Water quality parameters from five regions of Bangladesh that may affect performance of arsenic removal systems.

Region	pH	TDS (mg/L)	Iron (mg/L)	Phosphate (mg/L)	Silicate (mg/L)	As (III)/As(Total) (mg/L/mg/L)
Bera	7.2	261.4	12.0	3.6	32.8	0.8
Hajigonj	7.7	255.8	2.4	8.8	16.1	0.6
Manikganj	7.3	497.5	11.4	0.0	21.5	0.7
Nawabganj	7.2	266.3	5.0	1.8	26.0	0.8
Faridpur	7.2	409.9	8.4	1.4	19.2	0.8

The data from Table 1 clearly indicates that the groundwater quality in Bangladesh varies regionally. It is of interest to note that the majority of the arsenic present in the groundwater is in the form of arsenic (III), which exists as the uncharged species in water at pH values less than 9.2 (Clifford, 1990). Literature reports that arsenic (III) removal efficiency is much less than arsenic (V) and also most media life is substantially less for arsenic (III) than for arsenic (V) (McNeill and Edwards, 1997, Clifford, 1990). Also of note is the high phosphate content of

waters from certain regions, phosphate would compete with arsenic for sorption sites thereby reducing filter life (Clifford, 1990). In the same note the background silicate in the water will also compete for sites with arsenic and affect filter life. High pH in certain region (pH>7.5) will also reduce sorption capacity of arsenic removal media thereby reducing life of filters based on sorption onto metal oxyhydroxides (Clifford, 1990).

4. Performance of the arsenic removal filters with respect to different regional groundwaters

The performance of the five different filters in different regions is shown in Figure 2. The results show that the volume of water that a filter can treat (*below 50 ppb, the allowable arsenic concentration in potable water as per the Government of Bangladesh Regulation*) varies from region to region. Effectively the filter life varies from region to region. This was the case for all the five filters. The ion exchange filter, TETRATREAT had the worst performance of all the treatment systemsin all regional groundwaters (refer to Figure 2D). This may be due to the high total dissolved solids (TDS) of the groundwaters in all regions tested. Literature reports that ion exchange for arsenic removal will not work in waters with TDS approaching 500 ppm (Clifford, 1990). The TETRATREAT small community filter could only treat 5847 liters of water at the most optimum performance area, Nawabganj. This would satisfy the needs for ten families for thirteen days and then would require regeneration. Frequent regeneration calls for added expense that the rural populations of Bangladesh can ill afford; not to mention, the required proper disposal of the regeneration water, which contains high concentration of arsenic and sodium chloride.

As expected, the metal oxyhydroxides performed substantially better. The Read-F household filter performed the best (refer to Figure 2B). At a minimum, the filter is able to produce 7778 liters of water thereby satisfying the cooking and drinking water needs of a family for six months. The indigenous SONO filter also performed well except for the aberration in Hajigonj (refer to Figure 2C). Expect for Hajigonj the SONO filter at the minimum could produce 8320 liters of water or satisfy the needs of a family for 184 days. Furthermore the SONO filter is easy to make with indigenous products at the cost of less than 600 Taka or 10 dollars US. Mechanistically the good performance of the SONO filter can be attributed to the combined mechanism of coagulation co-precipitation and adsorption. Literature reports that coagulation systems generally remove more arsenic in a mole of coagulation basis than by adsorption alone (McNeill and Edwards, 1997).

Although the SIDKO system produced the maximum volume of arsenic free water 238,156 liters of water; this would satisfy the demands of 50 families for 106 days. However, at the cost of 228000 Taka or 3,800 US dollars in a country where the per capita income is only 250 dollars, this may not be a cost effective option.

A very important point of operational interest regarding the performance of all the filters was that all the filters failed very early in Hajigonj. The Hajigonj groundwater had high phosphate levels along with background silicate; compounding this, was the high pH of the water. These water quality conditions severely reduce the life of the filter due to decrease in positive adsorption sites above pH of 7.5 and phosphate and silicate concentrations, a thousand folds higher than arsenic (refer to Table 1) competing for the existing adsorption sites. Table 1 also shows that the groundwater in Bangladesh has high arsenic (III) (arsenite) content. Literature reports although arsenic three is removed by metal hydroxides by adsorption the efficiency and the filter capacity would be less than if the arsenic was in oxidation state five (arsenate) (Clifford, 1990, McNeill and Edwards, 1997). This is due to the fact that the arsenite species below a pH of 9.2 is uncharged. Thus the capacity or life of the filters deployed in

Bangladesh could greatly be increased by oxidizing the source water to convert the arsenite species of arsenic to the negatively charged arsenate species of arsenic at the near neutral groundwater pH observed in Bangladesh.

5. Conclusions

The performances of the filters are dependent on the groundwater quality matrix and, therefore, the performance of the filters (filter life) will vary from region to region. Application of ion exchange filter technology may be limited due to the high content of TDS in the Bangladesh groundwater. Filters based on sorption onto metal hydroxide perform better in Bangladesh groundwater provided that the pH is less than 7.5 and the phosphate content of the water is also low. In regions with high pH, background silicate, and high phosphate content, the life of metal hydroxide filter may be greatly reduced.

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