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A Comparative Study of Household Groundwater Arsenic Removal Technologies and their Water Quality Parameters

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Abstract: Groundwater arsenic contamination is one of the most important concerns in Bangladesh. We performed a comparative study of three available groundwater arsenic removal methods used in Bangladesh. Among the three methods, the Three-Pitcher system removed arsenic up to 96% whereas AAN-Filter and NIFSF methods removed arsenic 88 and 84%, respectively. The arsenic removal efficiency and water flow rate decreased significantly after three-month continuous operation in Three-Pitcher and AAN Filter methods and two-month continuous operation for NIFSF method. Calcium concentration was decreased to half by Three-Pitcher and AAN Filter methods but increased substantially in the NIFSF method due to the addition of bleaching powder. Anion concentrations in the filtered water changed in both directions. A significant increased in chloride was found in NIFSF water probably due to the chlorination of bleaching powder. Total Dissolved Solid (TDS) decreased 63 and 58% in Three-Pitcher and AAN Filter methods, respectively and increased 25% in NIFSF method. Considering all of the parameters, Three-Pitcher method was the best, but the others were effective, too. The choice of methods largely depends on the socio-economic conditions of the rural people. Before recommending any method for large-scale use in arsenic removal, further study needs to be done.

Key words: Ground water, contamination, arsenic removal, household level, Bangladesh

INTRODUCTION

Arsenic contamination of water sources has been reported for a number of countries, the contamination scenario in Bangladesh and in the West Bengal of India appears to be the worst detected so far world-wide, both in terms of area and population affected (Ali *et al*., 2001). Arsenic pollution of groundwater is particularly challenging in Bangladesh since tube well water extracted from shallow aquifers. This tube well water is the major source of drinking water for most people in Bangladesh. Chakraborti *et al.* (1999) reported that 30% of the tube wells contain arsenic above the permissible Bangladesh standard of 0.05 mg L^{-1}. Recent findings by the British Geological Survey (BGS, 1999) showed that groundwater of 61 surveyed districts, out of a total of 64, were contaminated with arsenic. However, survey results of the School of Environment Studies and Dhaka Community Hospital showed that 47 districts were contaminated (SOES/DCH, 2000). An estimated population exposed to arsenic concentration above the Bangladesh drinking water standard vary from about 20 million to 36 million (DPHE/BGS, 2000). In a recent survey conducted in 270 villages of Bangladesh, more than 7000 arsenicosis patients were identified (Rahman *et al*., 2000). Arsenic toxicity has no known effective treatment, but drinking of arsenic free water can help arsenic affected people at early stage of ailment to get rid of the symptoms of arsenic toxicity. Therefore, the most important measure is needed to prevent from further exposure of population by providing them with arsenic-free safe drinking water.

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In view of the overwhelming dependence of the population on groundwater, developing of suitable treatment system for arsenic removal from groundwater appears a promising option for providing safe water to the rural population. Socio-economic conditions of Bangladesh demand low-cost as well as small-scale treatment systems that could be implemented in the rural areas at household or community levels. But it is very difficult to select a unique method for arsenic removal. Some are effective but not economically feasible; some are economically feasible but not so effective. Some are not user friendly, technologically not sound, energy depended, require post treatment and skilled man-power, yet the quality of treated water fails to reach acceptable standards (Saha *et al*., 2001). Among the various technologies, the most commonly used technologies include co-precipitation with alum or iron, adsorption filtration (e.g. using activated alumina), ion exchange and membrane process such as reverse osmosis. Based on available information and experience on arsenic removal in Bangladesh, it appears that the Three-Pitcher, AAN (Asia Arsenic Network) Filter and Natural Iron and Fine Sand Filter (NIFSF) methods are the most common, sustainable and promising methods. The objective of the present study was to compare the performance and water quality standard of these three methods.

MATERIALS AND METHODS

Water samples used for arsenic removal were collected from the residential area shallow tube wells near airport road at Jessore district town (between 20° and 23° north latitude and 88° and 89° east longitudes) in Bangladesh during April- August, 2004 (Fig. 1).

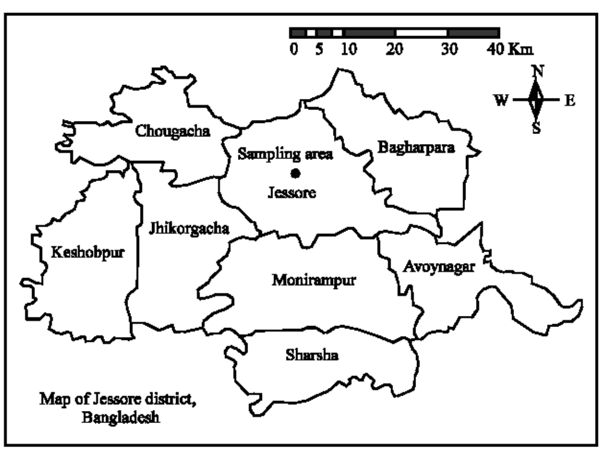

Fig. 1: Location of sampling area in Jessore district, Bangladesh

This area represents as one of the most contaminated areas across Bangladesh. In this area, the arsenic concentration ranged from 0.1-0.46 mg L^{-1} which is much higher than permissible limit of 0.05 mg L^{-1}. The water samples were collected from hand pumps tube well having the depth of 60 m. The geology around the tube wells and in the depth of about 100 m is investigated to be mainly composed of Upper Holocene Sediments. The methods for arsenic removal used in the field level in Bangladesh were: (1) Three-Pitcher method, (2) Asia Arsenic Network (AAN) Filter method and (3) Natural Iron and Fine Sand Filter (NIFSF) method. After arsenic removal using these three methods, the water sample was collected in 100 mL plastic bottles in every month (3 samples/month in each method). Bottles were properly labeled, tightly sealed and preserved in refrigerator. After four-month collection, all the water samples were brought to the Laboratory of Environmental Planning in Rural Area, Tottori University, Japan for performing water quality tests in August 2004. One untreated water sample from the same source was also analyzed in the same laboratory. In each month, water flow rate (L h^{-1}) was also recorded. The details of these three methods are described below.

Three-pitcher method: The filtration system described here and in the earlier report (Khan *et al*., 2000) was based on fire unglazed clay pitchers (hereafter called by its local Bengali name Kolshi) used by more than 80% of the population as reservoir for drinking and cooking water. In a three Kolshi filtration system, the Kolshis (top, middle and bottom) were placed on the top of each other in a steel or bamboo frame for ease of maintenance (Fig. 2).

Each Kolshi had a volume of about 18 L. The top and middle Kolshis had small holes at the bottom (0.5 cm diameter), which were covered with pieces of synthetic (polyester) materials from inside. The holes were made for free junction nozzles connected from outside. These nozzles could be easily altered to adjust flow rate. About half kilogram of small brickette pieces (grade A red bricks, 2-3 cm pieces) were spread on the clothes. The middle Kolshi was then fitted with 2 kg coarse sand, 1 kg wood charcoal (1 cm pieces from cooking wood) and 2 kg brickette pieces. The top Kolshi had 3 kg of cast iron turning (from local machine shop or iron works) placed uniformly on the brickette and 2 kg of sand on top of the iron turning. All the filtering materials were pre-cleaned to remove any unwanted dirt before the filter unit was assembled. Each 15 L tube well water was poured slowly on the top Kolshi at 5-7 h interval and collected at the bottom Kolshi. The filtration system was used for pure drinking water after discarding initial 3-4 batches of water. Experience showed that covering the middle and bottom Kolshis with small pieces of synthetic clothes placed on

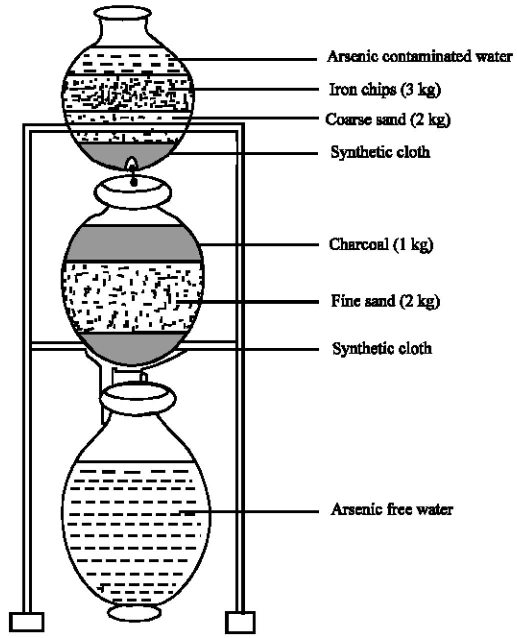

Fig. 2: Three-pitcher arsenic removal system (Khan *et al.*, 2000)

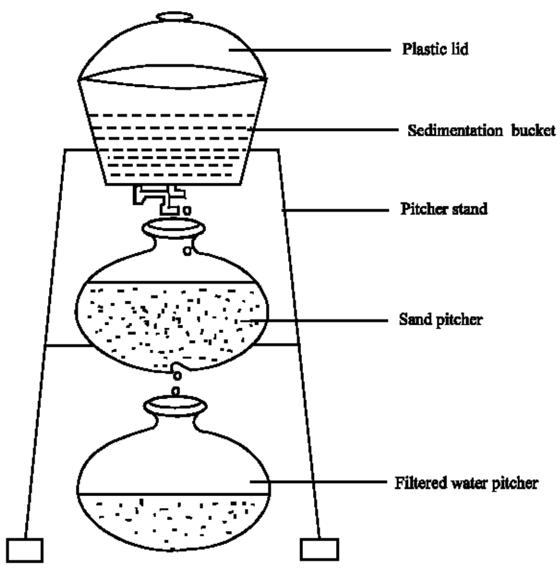

Fig. 3: AAN filter arsenic removal system (Asia Arsenic Network, 2001)

perforated earthen covers could prevent accidental leakage and dust. The filtered water was collected for analysis by decanting into pre-washed HDP (high density polyethylene) sample collection bottles and analyzed for trivalent arsenic (As III), pentavalent arsenic (As V) and other standard water quality parameters.

Asia Arsenic Network (AAN) Filter method: AAN Filter was based on aeration, sedimentation and filtration techniques for arsenic removal. Aeration mainly takes place before sedimentation by pouring and stirring of water in the top bucket. This method consisted of an 18 L plastic bucket and two clay pitchers (Fig. 3).

The upper bucket was covered with a plastic lid and tap. The top bucket contained iron fillings and the middle pitcher contained 2 kg of course sands. The third pitcher was for collecting the filtered water. Top bucket and middle pitcher had small hole in the bottom to facilitate drainage of water from one pitcher to other. A steel frame was used to support the middle and top pitcher. At first, 15 L arsenic contaminated water was poured on the top bucket and same amount of water refilling was done in 13-15 h interval. Then water was stirred for 2 min (40-50 times) and allowed to settle for 6 h. Lastly, the water was decanted through the tap and collected at lower pitcher. Finally pure water was drawn from the tap in the lower pitcher.

Natural Iron and Fine Sand Filter (NIFSF) method: This method was developed by NGO Forum, Bangladesh. It was based on aeration, sedimentation, flocculation and filtration system using natural iron present in water and fine sand filter. The system consisted of a 35 L plastic bucket and two 15 L pitchers (Fig. 4).

A steel frame tripod stand was used to support the first bucket and second pitcher. One tap, a washer, a rubber washer and a leak pipe were placed under the 35 L bucket for drainage water to second pitcher. A small mesh was used on bottom hole of the second pitcher. Then, 10 kg of clean and dry fine sand were placed in the second pitcher.

At first, 30 L arsenic contaminated water was poured in the 35 L plastic bucket was mixed with 2 g bleaching powder (65%) and aerated by stirring for at least 2 min. Water refilling was done in 13-24 h interval. After aeration, arsenic reacts with natural iron present in water to form small flock (insoluble compounds of Fe (AsO_4)). After preservation for 12 h, all flocks were sedimented in the bucket and 30 mL water per minute was collected in second pitcher by opening the tap. About 30 L of arsenic free water was collected per day. Proper care was taken for maintaining good aeration, sedimentation and filtration rate. One month later the sand was washed with arsenic free water and sun-dried for possible reuse.

Analytical methods and procedure: Concentration of arsenic, pH, electric conductivity (EC), temperature, Fe^{2+}, Ca^{2+}, Na^{+}, K^{+}, Mg^{2+}, Mn^{2+}, Cl^{-}, F^{-}, NO_3^{-}, PO_4^{3-}, SO_4^{2-},

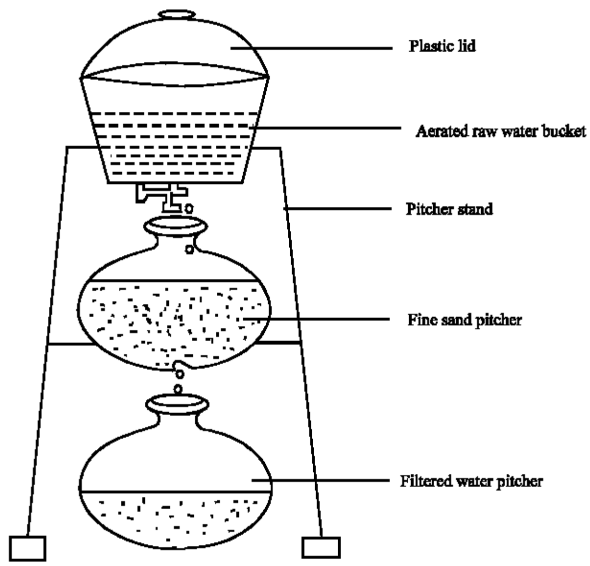

Fig. 4: NIFSF arsenic removal system (NGO Forum Bangladesh, 2003)

were analyzed in order to compare with standard water quality. Anions were analyzed by Ion Chromatography (Model I C 25, Dionex, Australia) and cations were analyzed by ICPAES (Inductively Coupled Plasma Atomic Emission Spectroscopy). Measurement of arsenic was performed by X-ray Fluorescence method using sodium benzyl dithiocarbamate (precipitation of heavy metals with di-benzyl di-thio-carbamate).

RESULTS AND DISCUSSION

Arsenic removal efficiency: Very good arsenic removal efficiency was achieved in all three arsenic removal methods tested. The arsenic removal efficiency and water flow rate of Three-Pitcher filter was reasonable up to three-month continuous operation but efficiency and water flow rate decreased substantially after three months (Table 1). After four months of continuous operation the Three-Pitcher filters showed some problems in terms of leaching of arsenic and clogging in iron fillings (Mudgal *et al*., 2000). In some cases it was found that iron fillings were clogged by forming a hard structure (hydrous ferric oxide), which could not be removed from the pitcher. In such cases the pitcher with sand and iron fillings was discarded and replaced with a new pitcher. As sand, charcoal, iron fillings, synthetic cloth and clay pitcher are easily available; it is easier for people to adopt this technology.

It was found in AAN Filter method that, both arsenic removal efficiency and water flow rate decreased greatly after three-month continuous operation and water from four month period gave arsenic more than permissible limit of 0.05 mg L^{-1}. For NIFSF method, arsenic removal efficiency was substantially decreased after two-month continuous operation and at third month, filtered water was found to be higher arsenic level than permissible limit (Table 1). So, it can be recommended as safety to use two-month and one-month continuous operations for ANN Filter method and NIFSF method, respectively. NIFSF method is newly introduced by NGO Forum and the use of this method is increasing in some extent in the South-western part of Bangladesh (NGO Forum, 2003). Due to its less durability in arsenic removal, it is not recommended for wide use in all over the country.

The initial arsenic content of water samples was 0.26 mg L^{-1} (Table 2). Arsenic removal efficiency was 96% in the Three-Pitcher method, 88 and 84% for AAN Filter and NIFSF methods, respectively up to three-month continuous operation. So these methods could be used for effective as removal from water environment up to certain extent over ions, such as Cl^-, SO_4^{2-}, PO_4^{3-}, NO_3^-, F^-, Ca^{2+}, Mg^{2+} and Fe^{2+}.

Quality of filtered water: Arsenic removal efficiency and water flow rates decreased substantially after three-month continuous operation of these three methods. Therefore, we only analyzed the filtered water up to three-month collection, which was averaged and presented in Table 2 and 3.

Analysis of the initial groundwater showed it contained high levels of Fe^{2+} as well as total dissolved solid (TDS). The maximum desirable concentration of iron in Bangladesh ground water is 0.3 mg L^{-1} and maximum permissible concentration is 1 mg L^{-1}. The levels of other elements such as Na^+, K^+, Ca^{2+}, Mg^{2+}, Mn^{2+}, Zn^{2+}, Cl^-, F^-, SO_4^{2-}, PO_4^{3-}, etc. were below the permissible Bangladesh water standard. Table 2 shows iron in water decreased significantly which was ranging from 0.01 mg L^{-1} to 1.93 mg L^{-1}. Khan *et al.* (2000) reported significant iron removal from 6.89 to 0.08 mg L^{-1} by Three-Pitcher method which supported our findings. Since a large part of Bangladesh (about 65% areas) groundwater contains excess iron of 2 mg L^{-1}. The concentration of iron is as high as 15 mg L^{-1} in many acute iron problem areas therefore, arsenic has been found to co-exist with iron in many situations. In such cases, arsenic can be removed by both co-precipitation and adsorption into the precipitated $Fe(OH)_3$ by oxidation of this water during collection and subsequently storing them in household level. Mamtaz and Bache (2000) from their bench-scale tests demonstrated that arsenic can be removed by co-precipitation with naturally occurring iron but removal rate largely controlled by the arsenic concentration, the iron/arsenic ratio and pH. It was

Table 1: Comparison of water flow rate and arsenic removal efficiency among Three-Pitcher, AAN Filter and NIFSF methods until 4-month continuous operation

	Flow rate ($L\ h^{-1}$)				Arsenic content ($mg\ L^{-1}$)			
Method	1st month	2nd month	3rd month	4th month	1st month	2nd month	3rd month	4th month
Three-Pitcher	2.750	2.700	2.610	2.100	0.004	0.005	0.026	0.032
AAN Filter	1.240	1.200	1.130	1.010	0.031	0.040	0.044	0.065
NIFSF	2.110	1.750	1.250	1.210	0.040	0.045	0.055	0.061
$LSD_{(0.05)}$*	0.258	0.203	0.248	0.189	NS	NS	NS	NS

LSD = Least Significant Difference, *Significant at 5% level

Table 2: Comparison of drinking water inorganic quality parameters (cations) after treated with Three-Pitcher, Asia Arsenic Network (AAN) Filter and Natural Iron and Fine Sand Filter (NIFSF) methods along with initial groundwater (average of 3 months samples)

Method	Flow rate ($L\ h^{-1}$)	Arsenic ($mg\ L^{-1}$)	Iron ($mg\ L^{-1}$)	Manganese ($mg\ L^{-1}$)	Calcium ($mg\ L^{-1}$)	Magnesium ($mg\ L^{-1}$)	Sodium ($mg\ L^{-1}$)	Potassium ($mg\ L^{-1}$)	Zinc ($mg\ L^{-1}$)
Groundwater	-	0.260	6.77	0.690	111.0	21.40	20.40	12.95	0.010
Three-Pitcher	2.6	0.010	0.01	0.002	56.00	21.20	26.10	38.89	0.001
AAN Filter	1.12	0.030	1.93	0.130	65.33	20.30	14.10	9.660	0.030
NIFSF	1.75	0.040	1.31	0.140	150.0	21.10	23.50	29.51	0.040
$LSD_{(0.05)}$*	-	0.003	0.029	0.023	5.790	0.225	0.208	0.234	0.021
Bangladesh standard	-	0.050	1	0.100	200	150	200	12	5

LSD = Least Significant Difference, *Significant at 5% level

Table 3: Comparison of drinking water inorganic quality parameters (anions) after treated with Three-Pitcher, Asia Arsenic Network (AAN) Filter and Natural Iron and Fine Sand Filter (NIFSF) methods along with initial groundwater (average of 3 months samples)

Method	pH	Temp. (°C)	Chloride ($mg\ L^{-1}$)	Fluoride ($mg\ L^{-1}$)	Nitrate ($mg\ L^{-1}$)	Sulfate ($mg\ L^{-1}$)	Phosphate ($mg\ L^{-1}$)	TDS ($mg\ L^{-1}$)
Groundwater	6.9	20	3.27	0.27	0.98	0.42	0.35	600.0
Three-Pitcher	7.7	21	5.90	0.47	0.72	0.41	0.07	220.0
AAN Filter	7.3	21	1.72	0.35	0.78	0.002	0.28	250.0
NIFSF	6.7	23	365.67	0.50	0.52	0.05	0.23	755.0
$LSD_{(0.05)}$*	-	-	2.049	0.027	0.042	0.011	0.021	24.78
Bangladesh standard	6.5-8.5	-	600	1	10	250	6	1000

LSD = Least Significant Difference, *Significant at 5% level, TDS = Total Dissolved Solid

evident from their test result that up to 88% of the As (III) in water could be removed by settlement over a period of 24 h. They collected arsenic contaminated natural groundwater having very high iron content from Manikgonj area. Samples were shaken during the time of collection and transportation and allowed to settle in the laboratory. This process removed more than 60% arsenic, where raw groundwater arsenic and iron concentrations were in the range of 150 to 713 $\mu g\ L^{-1}$ and 8 to 14 $mg\ L^{-1}$, respectively.

Iron is present in the filtration system as zero valent iron, FeO, in the top pitcher and in groundwater mostly as soluble Fe(II) species. In both cases, the excess arsenic removal capacity increases linearly after each pitcher of filtration. Soluble iron, primarily present as Fe(II) in groundwater plays a very significant role in removing arsenic and other trace cations and anions. In contact with air Fe(II) is oxidized to Fe(III) and precipitates as $Fe(OH)_3$, hydrous ferric oxide (HFO: Fe_2O_3, 2-3 H_2O), $Fe(HCO_3)_2$ etc. Moreover, As (III) and As (V) are strongly absorbed by Fe $(OH)_3$, HFO and Goethite. Since the filtered water is nearly free from iron, therefore the oxidation products of zero valent iron and the oxidation of Fe(II) species to HFO are quantitatively retained in the top and middle pitcher (Munir *et al.*, 2001). This is due to the accumulation of HFO formed from freshly available soluble iron in groundwater. At the end of the present Three-Pitcher experiment, it was found that Fe0 in the top pitcher was turned into a solid cemented brownish iron oxide with visible pores throughout the mass. It was clear that extensive oxidation of Fe(0) took place inside the pitcher, which was sustained by a continuous diffusion of air and water vapor through the porous ceramic pitcher.

Arsenite in the presence of zero valent iron, Mn^{2+} in groundwater and MnO_2 in the sand is catalytically oxidized to arsenate in the heterogeneous media (Khan *et al.*, 2000). The concentration of Mn^{2+} also decreased to less than 0.002 $mg\ L^{-1}$ in Three-Pitcher method. Therefore, these two metals were quantitatively removed by the filtration system as their hydroxide precipitates. The three months variation of Fe^{2+} was 0.006, 0.009 and 0.015 and that of Mn^{2+} was 0.001, 0.002 and 0.003. These variations occurred due to the decrease of air space within the bucket. Because sediment increased with time and as a result aeration possibility decreased. The concentration of Ca^{2+} was decreased to about half by the Three-Pitcher and AAN Filter methods but increased substantially in the NIFSF method. The reasons might be the use of bleaching powder, which released additional Ca^{2+} into the water treated by the NIFSF method. It may be noted that in high iron concentration, a high concentration of Ca^{2+} on HFO increases the positive charge density of the HFO colloids and thus enhances adsorption of AsO_4^{3-}. The concentration of Mg^{2+} remained unchanged in all three methods. A small increase in alkali metal ions (Na^+ and K^+) concentration (Three-Pitcher and NIFSF methods) is indicative of a low-level ion exchange of these ions in silicate sand minerals with that of alkaline earth cations. But in AAN filter method it was decreased substantially. Zinc concentration was markedly increased in AAN Filter and NIFSF water.

The pH of the filtered water increased from 6.9 to 7.7 possibly due to decarbonation in Three-Pitcher method. On the contrary, it decreased slightly in the NIFSF method due to chlorination by bleaching powder. Anion concentrations in the filtered water changed in both directions. A significant increment in chloride was found in the NIFSF water probably due to the addition of bleaching powder. The amount of fluoride increased significantly in NIFSF method followed by Three-Pitcher method. The amount of nitrate decreased in all the methods. Sulfate increased in Three-Pitcher method but decreased in AAN Filter and NIFSF methods. Phosphate decreased in all three methods. Total dissolved solid (TDS) decreased 63% in Three-Pitcher and 58% in AAN Filter methods whereas increased 25% in NIFSF method (Table 3). Khan *et al*. (2000) tested the performances of Three-Pitcher method and water quality parameters by ICPAES measurement and reported similar amount of arsenic and significantly lesser amounts of Fe^{2+}, Mn^{2+}, Mg^{2+}, Na^+, K^+, Cl^-, F^- and TDS. But, they found slightly different results in other cations and anions. NGO Forum (2003) reported similar results in amounts of arsenic, Fe^{2+}, Mn^{2+}, Mg^{2+}, K^+, Cl^-, NO_3^-, PO_4^{3-} and TDS in AAN Filter and NIFSF methods. The other cations and anions differed in both directions for these methods. These differences might be due to the different source, depth and collection time of water samples used in filtration system. Except for occasional variations in non-toxic species (Fe^{2+} and Na^+), and change in flow rate, the Three-Pitcher system performed well. In some cases, the system may not function adequately due to clogging of the outlets and overloading of sand with fine hydrous ferric oxide (HFO:Fe_2O_3.2-3H_2O) properties (Munir *et al*., 2001).

Cost of three methods and their utilities: The cost of Three-Pitcher filter unit is about US $ 5 (Munir *et al.*, 2001) compared to the cost US $7 for NIFSF system (NGO Forum, 2003) and US $18 for AAN Filter system (Asia Arsenic Network, 2001). Three-Pitcher filter is inexpensive, easy to assemble with locally available materials and without adding chemicals. It is based on an indigenous technology known to people from several decades. At its present capacity, five people (10 L/person) can use the system for about five months at a consumption rate of 50 L/day (flow rate of 2.1 L/h). Regeneration of the system to its original efficiency can be achieved by changing the sand in the pitcher (Munir *et al*., 2001). Khan *et al*. (2000) reported that the Three-Pitcher filter could remove arsenic from groundwater which containing a wide range arsenic concentrations (0.08-1.0 mg L^{-1}). But, there is a potential problem of clogging with iron, particularly if the filter is allowed to dry out between uses.

The main reasons why some technologies are not acceptable to the users are the amount of work needed to operate and maintain the technologies, the amount of time that they have to wait for water and the volumes of water that are available on a daily basis (Sutherland *et al*., 2001). The work required for the Three-Pitcher was less than for other technologies and the volume of water produced by this method was more than other technologies.

The AAN Filter's cost is much higher for most of the rural households. The filter can be assembled at the household level with locally available materials. It is easy to operate and portable and can yield 30 L of clean water per day. AAN Filter can be used continuously for two months before the need to remove the sand in the second pitcher. Many filters could be out of use due to problems such as disintegration of filter, breaking of taps, clogging of filter (hydrous ferric oxide) and reduction in arsenic removal capacity after use for two months.

The NIFSF method is also cost effective and easy to handle, which can be assembled with locally available materials. However, we could not use this method if the arsenic percent in water exceeds 0.26 mg L^{-1} (NGO Forum, 2003). And the arsenic removal efficiency is very low when the natural water contains a low level of iron. Proper packaging and storage particularly of bleaching powder having a very limited shelf life (only 2 months) is another challenge to use this system.

Arsenic removal technologies use water from existing contaminated wells. Hence, the costs of arsenic removal technologies do not include the cost of the wells, it may be observed that cost of arsenic treatment is very high and is beyond the reach of the low-income villagers. The cost of arsenic removal with iron by simple aeration-filtration is comparatively low but the efficiency of the method is dependent on the presence of iron and optimum alkalinity in natural water as reported by Mamtaz and Bache (2000). Verification of some arsenic removal technologies in Bangladesh showed that the performances of the technologies are very dependent on pH and presence of phosphate and silica in natural groundwater and most technologies do not meet the claims of the proponents in respect of treatment capacity

(BCSIR, 2003). A reduction in the rated capacity will further increase the cost of treatment per unit volume of water.

CONCLUSIONS

Treatment of arsenic contaminated water for the removal of arsenic to an acceptable level is one of the options for safe water supply. A lot of effort has been mobilized for treatment of arsenic-contaminated water to make it safe for drinking as increased detection of arsenic in groundwater has occurred. During the last few years many small scale arsenic removal technologies have been developed, field tested and used under different programs in developing countries like Bangladesh. Treatment of arsenic-contaminated water, in contrast to many other impurities, is difficult and it becomes much more difficult for rural households supplied with scattered hand pump tube wells. On the other hand removal technologies so far tried for the rural people have potentials but not tested thoroughly for adoption. Most of the rural people are illiterate. They accustomed to drinking hand tube wells water during the last 30 years. Therefore, any change in their behavioral needs more friendly approach and technology.

Three-Pitcher system appears to be the best option and sustainable in rural areas, but the others are effective, too. We believe Three-Pitcher system can be very effective for filtration of toxic groundwater in Bangladesh and in many parts of the world where clay pitchers are used for preserving drinking water. But the choice of methods largely depends on the socio-economic conditions of the rural people. The cost of arsenic removal technology is an important factor for the adoption and sustainable use in the rural context. The cost of the technologies depends on many factors such as the materials used for fabrication of components, quantity of media/chemicals used, quality of groundwater etc. Hence, the costs of installation, operation and maintenance of all the arsenic removal systems are not yet known or need to be standardized based on modifications to suit the local conditions. However, the criteria of sustainability and acceptance by rural users must be incorporated in the calculation of cost effectiveness, in order to aid the decision making process over which mitigation methods to implement.

Several government and non-government organizations have been working for developing suitable methods for arsenic removal from drinking water. But, only few methods are available in field level depending on the less complexity and operation friendly for rural people. Further studies would be required to find the system for wide adoption in Bangladesh.

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