Natural Arsenic in Groundwater: Occurrence, Remediation and Management – Bundschuh, Bhattacharya and Chandrashekharam (eds)
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Sustainable safe water options in Bangladesh: Experiences from the Arsenic Project at Matlab (AsMat)

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ABSTRACT: The presence of elevated levels of naturally occurring arsenic in groundwater of Bangladesh, has severely impaired the decade long effort of providing safe water to nearly 98% of its population and putting an estimated 35 million people-nearly one fourth of the total population –at risk. In order to address this problem, a project titled "Arsenic in tubewell (TW) water and health consequences in Matlab Upazila of Chandpur district (AsMat)" is being implemented jointly by ICDDR,B and BRAC. During this study. all the TWs in Matlab have been assigned unique identification numbers, with marked GPS coordinates, depth, and age. It is estimated that nearly 65% of the about 13.000 TWs in Matlab have As concentrations above the Bangladesh drinking water standard (50 μg/L). In order to minimize arsenic exposure, a work to provide various alternate safe drinking water options to the exposed population has been initiated. As of March 2004, about 1,047 different alternate safe water options, such as Pond Sand Filter (PSF), Rainwater Harvester (RWH) and different filters to remove arsenic as well as pathogenic bacteria, were distributed among the targeted exposed population in Matlab. To ensure sustainable use, the provided options were assessed based on community acceptability, technical viability, and financial viability.

1 INTRODUCTION

The arsenic problem in Bangladesh has been described as the largest mass poisoning in history (Rahman et al. 2001, Smith et al. 2000) Chronic ingestion of inorganic arsenic causes characteristic skin lesions as observed in populations in Bangladesh and elsewhere. The presence of arsenic above the Bangladeshi limit of safe drinking water (50 μg/L, WHO 2001) was first detected in groundwater of the Bengal Delta Plain (BDP) aquifers in Bangladesh in 1993 (Bhattacharya et al. 1997, 2002, 2004, Nickson et al. 2000, Smedley & Kinniburgh 2002, Ahmed et al. 2004). This has resulted in a severe environmental disaster affecting several million people in the region, as groundwater is the main source of potable water for nearly 98% of the population in Bangladesh. What was a success story is now poised to threaten the lives of millions of people living in 61 out of the 64 districts in Bangladesh (Figure 1). Given the present scenario of safe water status, it would not be possible for Bangladesh as well as other arsenic affected parts of the globe to ensure the target of the Millennium Development Goals of ensuring safe drinking water supply to its inhabitants by the year 2015, if necessary measures are not taken on an urgent basis to alleviate the crisis.

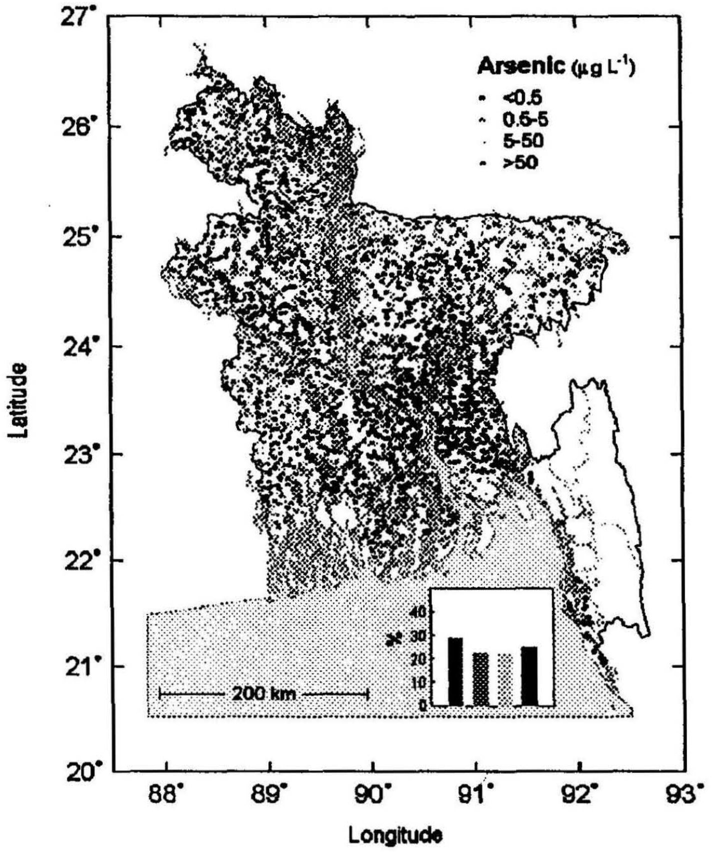

Figure 1. Distribution of arsenic in Bangladesh (DPHE/BGS/DFID 2000).

Though elevated As levels in the groundwater in Bangladesh were detected in the early 1990's, it has only received adequate attention since 1998. The Government of Bangladesh, non-governmental organizations (NGOs) and donors are working together to address this critical issue. The As contamination in the groundwater of Bangladesh poses five major challenges for action (Table 1)

Table 1 Five major challenges for arsenic mitigation in Bangladesh

- ❑ Test all tube wells for arsenic; there are about 8-10 million such wells in Bangladesh
- ❑ Investigate the mechanisms of arsenic contamination of groundwater;;
- ❑ Identify people with elevated risk of arsenic toxicity. A variety of toxic effects, including different types of cancers (most of which are not likely to be reversible)
- ❑ Provide alternative arsenic-safe water options which are culturally acceptable, technically feasible, environmentally safe, and affordable by common people;
- ❑ Research into the extent of soils contamination due to irrigation with arsenic-contaminated groundwater that may affect the food chain.

The most daunting challenges among the above are those of testing of the wells, finding alternative sources of safe water, and identification of people at highest risk of arsenic exposure. BRAC in conjunction with ICDDR,B and collaborating institutions in Sweden, is implementing a project at Matlab upazila of Bangladesh to address arsenic and its remedial issues. This project is benefiting from ICDDR,B's Health and Demographic Surveillance System in 142 villages in Matlab. The surveillance system contains demographic information, reproductive outcomes, health and nutritional information, which are linked with a geographic information system. The project activities started in 2001 and will continue till 2006. Some preliminary findings on the mitigation are presented here.

2 MATERIALS AND METHODS

2.1 The AsMat study area

Matlab is situated 53 km south east of Dhaka, accessible by road and river transport (Fig. 2). The location of Matlab is highly affected by the sedimentation process of As laden soil, as it is situated near the Meghna River, where it joins the confluent streams of the Brahmaputra and Ganges rivers. The area is a low-lying delta plain intersected by branches of the rivers and numerous canals. During the monsoon most of the land is flooded, except for clusters of houses built on earthen mounds. In 1988-89, a 60-km long embankment was built alongside the bank of the Dhonagoda and Meghna rivers. The embankment was built primarily to protect the area from monsoon flooding so that agricultural activities might be carried out throughout the year. ICDDR,B is running a health and demographic surveillance system in 142 villages of the Matlab upazila, encompassing a 220,000 population in 18,386 hectares of land.

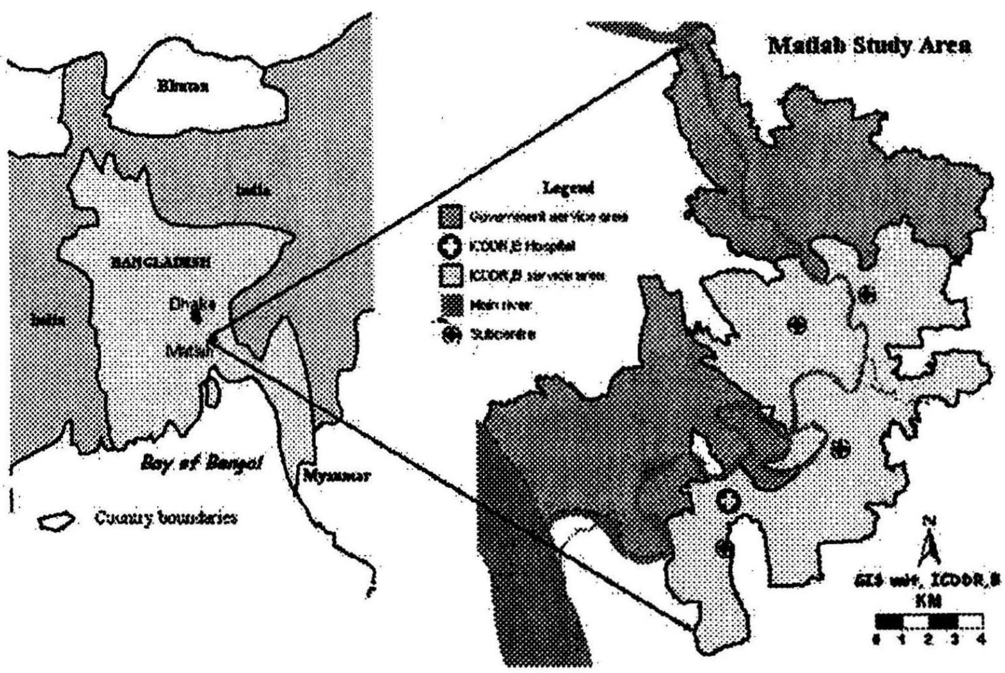

Figure 2. Location map of the AsMat study area

2.2 Screening of TWs

Geographical coordinates of all the identified TWs in AsMat study area were recorded using a handheld Global Positioning system (GPS) unit. Testing TW water to identify TWs, with low arsenic concentrations (less than the Bangladesh drinking water standard, 50 µg As/L), is the first step in reducing the magnitude of As contamination for the millions of exposed population in the country. To date, more than a million wells in Bangladesh have been tested using field kits (Rahman et al. 2002). The wells with As levels >50 ppb were painted red to indicate that the water is unsafe for drinking, and those with levels <50 ppb were painted green to indicate that the water is safe. However, it should be pointed out that arsenic concentrations 50 ppb still possess a very high cancer risk, compared to what is recommended by the WHO (WHO, 2001) for an environmental pollutants such as arsenic. In the Matlab study area, a total of 13,302 TWs were tested using the Merck field kit and were numbered and classified as to geographical coordinates by Geographic Positioning System (GPS).

Field teams consisting of a field research assistant from ICDDR,B and *Sasthya Sabika* (Health workers) from BRAC performed the testing of TW water for As (Chowdhury & Jakariya 1999). Earlier, they were given a one-week extensive training on how to test TW water and on different deliverable messages regarding arsenic to be disseminated among villagers after testing of TW water. Tubewells were purged adequately (20/30 strokes) prior to testing with the Merck field kit and collecting a sample for laboratory analysis. One Merck field kit is capable of performing ca. 80 tests and costs around $50, giving an approximate price of $0.63 per test. The Merck kit uses a semi-quantitative colorimetric method. Both arsenate and arsenite species present in the water samples are chemically converted to arsine gas, which reacts with a mercury bromide impregnated test paper stripe and produces a color that correspond to the amount of As present in the sample.

2.3 Community involvement

Although the presence of elevated levels of As in groundwater has been known since the beginning of 1993, there is a substantial need to raise the awareness among the population about the health risks associated with long-term ingestion of contaminated groundwater through drinking. Awareness raising and motivation on As issues were done in two ways. First, people are made to understand that As is highly toxic, and second, people are told that they should procure safe water at their own effort and cost. A combination of approaches such as staging popular theatre, meetings, organizing workshops, and showing video are being used to raise awareness about As contamination and the consequences of drinking As contaminated water (Hossain et al. 2003).

Sustainable development cannot be achieved without involving the local community in the planning and development processes. The local inhabitants were involved in implementing the project. Multiple meetings at the village level were held at different stages of the project to inform and involve the community. At these meetings potential safe water options were discussed. The villagers decided where the community-based systems would be best located and then committed to maintaining the system.

2.4 Providing alternative safe water options

Installation and assessment of safe water options were major activities of the mitigation component of the project. Obviously, arsenic free water is the main way to reduce the risk of arsenic toxicity (Jakariya et al. 2003, Claudia et al. 2000). It may be noted that the options installed in Matlab are based on BRAC's previous experience of providing alternative safe water options to other arsenic exposed populations of the country. Specific criteria were used while targeting households for alternative options (Table 2).

The next priority, in terms of providing safe water options, has been given to the villages where 50% or more of the TWs were found to be contaminated with As. Within the village, families with poor socioeconomic condition were given priority for distribution of home-based options. The community-based options are constructed in places where most of the TWs are contaminated.

It was decided that the alternative options distributed in the project areas should not be free of cost. The community or the individual (in the case of household-based options) should have to contribute at least 20% of the total installation cost, either in cash or in kind, according to the inclination of the individuals. It was observed that the community preferred to pay their contribution part in kind (e.g. paying the carrying cost of construction materials, arranging lodging facility for the mesons during construction period, etc), particularly for the construction of PSF and RWH system.

Table 2. Criteria for distribution of the safe water options

- Willingness to bear 20% of the installation cost and 100% operation and maintenance cost
- Water As concentrations in the village
- Symptoms of arsenic toxicity in the village
- Poor socioeconomic condition

2.5 Monitoring of water quality

The water quality of the provided options was monitored both for arsenic and bacterial contamination. A monthly plan has been developed to check water quality of the randomly selected options before and after treatment of water to see the technical viability of the provide options.

3 RESULTS AND DISCUSSION

3.1 Arsenic mapping

Out of the total 15,884 TWs in the project area, only 13,302 functioning TWs were identified and tested for As contamination using field kits. About 65% of the total tested TW waters indicated As concentrations at levels exceeding the Bangladeshi permissible limit (i.e. 50 ppb) and about 9% of the total TWs tested had As levels over 500 ppb.

With the help of these GIS maps, highly As contaminated pockets were efficiently targeted for distribution of alternative safe water options. This piece of information was useful to target not only the vulnerable areas but also to demonstrate safe water options to the wider community for their own understanding as well as for decision making with respect to the best suitable options for themselves (Figure 3).

3.2 Arsenic concentration in relation to depth and age of TW

An attempt was made to assess whether there was any relationship between depths of TWs and the level of As contaminations as it was well known that As concentration decreases with depth (JICA 2002, BGS 2000). As shown in Figure 4, there was a statistically significant association between depth of TWs and the As concentration ($p < 0.01$). More than 14% of the TWs within 17m depths were found to have low arsenic concentrations. As contamination was found to be highest (more than 95% TWs) within the depth range of 17-67m, and almost 100% TWs were found to be within Bangladeshi drinking water standard (BDS) beyond 67m deep (Figure 4). The conclusion that can be drawn from these results is that the probability of getting water with low As concentration is at depths more than 67m in this area.

Large-scale installation of TWs in Bangladesh was initiated in the early 1980s, when people decided to install their own TW for access to safe and clean water or to gain prestige. However, almost 82% of the present TWs in Matlab were installed during the last 10 years (Figure 5). As shown in Figure 5, As concentrations are higher in older TWs.

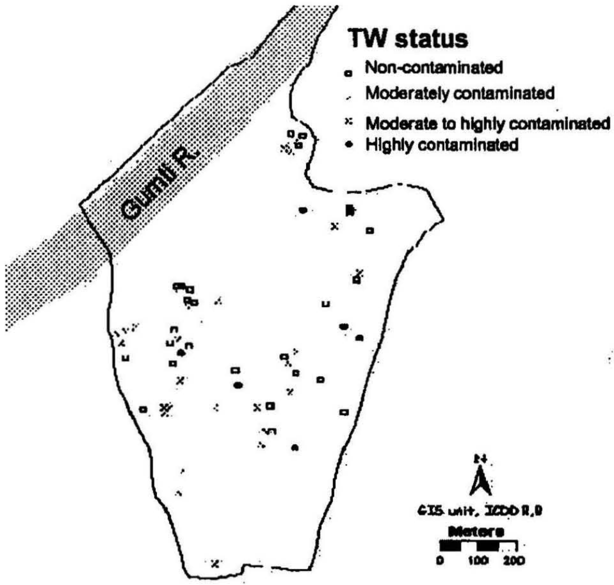

Figure 3. Distribution of TWs and their status of As concentration in groundwater in a village of AsMat study area.

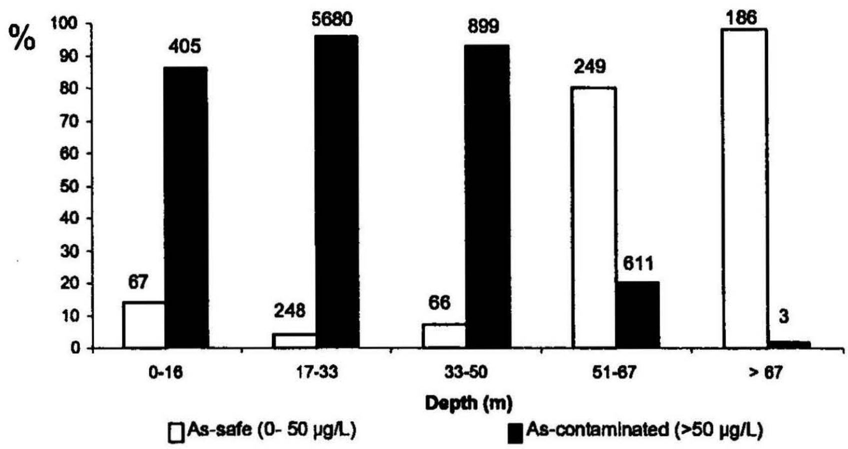

Figure 4. Variation of As concentration with depth of the tubewells

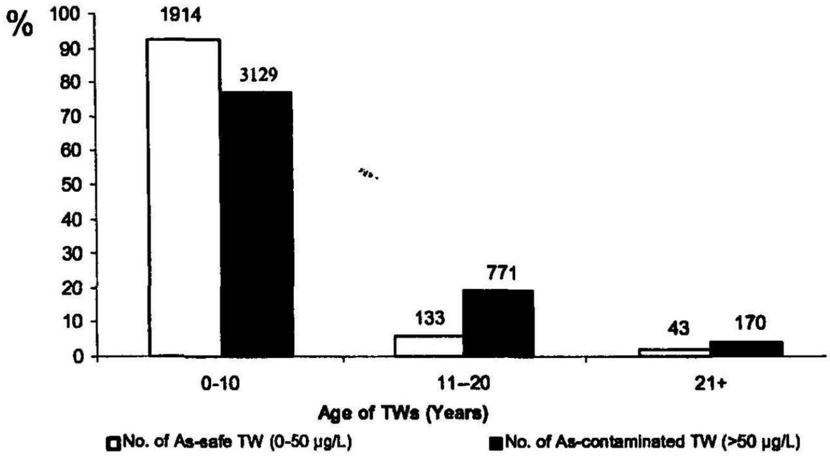

Figure 5. Percentage of arsenic contaminated TWs with the year of installation

4.1 Alternative water option

The main options promoted (BRAC 2000, Jakariya et al. 2003) were: i) treatment of surface water with community-based Pond Sand Filter (PSF) and home-based Bishuddhya filter; ii) collection of rainwater in Rain Water Harvesters (RWH); iii) treatment of As contaminated groundwater with home-based three-pitcher filters, Alcan filters and Safi filters (Table 3) The number of total exposed families in Matlab is about 26,650. About 54% of the exposed families obtained water from the green marked TW and another 13% were drinking water from different types of alternative water options already installed/distributed in Matlab. The remaining families were to take advantage of evaluations of existing options in their areas.

Before testing TW water for As contamination in Matlab, it was observed that about three families shared one TW. The number of families covered by green marked TWs were calculated based on this statistic. But recently we conducted a survey in several villages of Matlab with the aim to know the number of users of green marked TWs (As-free). According to the survey, the number of users of green TW has increased from three to seven, which indicates most of the exposed families are at least trying to collect water from different available safe water sources, primarily from the green marked TWs.

The options presented in Table 3 are being assessed on several criteria: initial and running costs; ease of implementation, running and maintenance; continuity and flow of supply; As removal capacity; susceptibility to bacteriological contamination; and acceptability to the community. It is not yet possible to draw general conclusions as to the sustainability of the provided options. A description of the different options provided in Matlab is presented in the following.

Table 3: Safe water options distributed in Matlab Upazila during the AsMat Project

Safe water options		Total number of options	Total families covered
Household based options			
	Three pitcher filter	99	99
	Alcan filter	653	653
	Safi filter	24	24
	Bishudhha filter	140	140
	Rainwater harvester (RWH)	115	115
Community-based options			
	Pond sand filter (PSF)	16	1,600 (100/PSF)
	Total	1,047	2,631

4.1.1 Description of the options

4.1.1.1 Pond Sand Filter (PSF)

In the coastal belt of Bangladesh, where salinity in the shallow groundwater is reported to be a severe problem, the Department of Public Health Engineering (DPHE) and UNICEF have installed slow sand filtration units linked. Hand pumps are used to deliver pond water to the units, which are called Pond Sand Filters (PSF). In this slow sand filtration system a bed of fine sand is used through which the water slowly percolates downward, resulting in the removal of pathogens through a combination of physical and biological processes. One PSF can supply the daily requirement of drinking and cooking water for about 40-60 families with a cost of about US$ 600. Once trained, masons with locally available materials can construct PSF. There is no chemical treatment involved in this process and little effect on the environment.

The greatest challenge for this option is to find suitable ponds which are perennial, free from pisciculture, and protected from using for bathing and washing clothes, cattle, etc. It has been reported that many of the PSFs constructed in the past in other arsenic affected areas where BRAC is providing As mitigation options, are now abundant as the owners' of the ponds restarted commercial fishing activities (BRAC 2000). Most ponds are privately owned and therefore, villagers have little to say about changing owners' decision about restarting commercial fishing activities in spite of having formal agreement with the community that they will reserve the ponds for drinking water use only. In Matlab, it can be noted that because of this type of practical problems only 16 PSFs have been constructed during the last two years. However, there is potential that PSFs could be one sustainable alternative to the arsenic problem in some areas.

4.1.1.2 Rain Water Harvester (RWH)

Rainwater harvesting is utilised in many parts of the world to meet the demand for drinking water. There is a long-established tradition of rainwater collection in some parts of Bangladesh, where shallow groundwater water has elevated salinity. Although the potential for rainwater harvesting is good in some areas of Bangladesh, the amount of rainfall varies widely across the country. Rashid (1977) shows that mean annual precipitation ranges from 1,400 mm (about 55 inches) along the country's central western border to more than 5,000 mm (200 inches) in the far northeast. The wet months are mid-June to late September and the dry period is from January to April. About 80% of the annual precipitation occurs in the monsoon period. Rainfall patterns were also confirmed with local communities in order to ascertain the feasibility of RWH, and alternatives and parallel use of other options were considered before constructing RWH jars in Matlab.

The capacity of a jar is about 32,000 litres and the cost is about US$ 130 (DPHE/UNICEF 1988-93). During the course of the project it was observed that the construction cost was too prohibitive to construct for an individual rural household. Monthly analysis for total coliform and faecal coliform bacteria to assess the safety level of the RWH water for drinking was done at laboratory and the results were found to be highly satisfactory.

4.1.1.3. Safi Filter

This household level filtration device was developed locally by Professor Sayeed Safiullah of Jahangirnagar University, Dhaka, Bangladesh. The Safi filter was designed to remove both As and pathogenic bacteria. The filters distributed initially had many problems in terms of flow rate and As removal efficiency (BRAC 2000). The Safi filter consists of two concrete buckets of 20 litre storage capacity, one of which is placed inside the other. The upper bucket is filled with TW water, which then flows through a permeable 'candle' and is collected in the lower bucket where it is stored. When needed it is drawn off with a tap. One small Safi filter is designed to filter approximately 40 litres of water per day. The cost of such filter is US$ 15.

The Safi filter candle is prepared from a chemical mixture of laterite soil, ferric oxide, manganese di-oxide, aluminium hydroxide and meso-porous silica. These materials adsorb arsenic as the water passes through the candle and thus the contamination is removed. It is also claimed that the candle eliminates pathogenic bacteria from the contaminated water. The manufacturers calculated that after two years of continuous use the candle would need to be replaced with a fresh one. Each new candle costs US$ 4.

4.1.1.4 Bishuddhya filter
This non-chemical based filter is basically designed to remove pathogen load from surface water. The filtration and purification technique used in this system is similar to PSF technology. *Bishuddhya* filters are relatively inexpensive and produced in Bangladesh. The main material used in this filter is different mesh sizes of locally available rocks and the water passes from the bottom through different layers to remove bacteria before it arrives at a storage chamber. The cost for this household-based device is US$ 45 with virtually no operation and maintenance cost, except for washing the materials after certain interval depending on the suspended loads of row water. The plastic container of this filter is made from food-graded plastic. The only precautionary measure that needs to be ensured here is that surface water must be obtained from a protected source to ensure no contamination with chemicals, fertilisers, etc. This filter could be an ideal option for areas where protected surface water is available and for southwestern part of the country where most people still use surface water for drinking and cooking purposes.

4.1.1.5 *Three-kolshi* or *three-pitcher* filter
The three-pitcher filter is based on an indigenous method of filtration, which has been used in Bangladesh for ages. Traditionally, two local clay pitchers (called *kolshi*) are used to filter water. The top pitcher is partially filled with sand and charcoal, and a small hole is made in the bottom. A piece of synthetic cloth is placed over the hole to prevent sand from spilling out. Water is passed through this pitcher to remove suspended matter from surface water and more recently to remove iron from TW water. After passing through the top pitcher, filtered water is stored in the bottom pitcher. Scientists from Bangladesh and the USA noted the potential of this simple method to remove As well. They modified the system by adding a third pitcher above the sand/charcoal pitcher, which is filled with iron filings to provide an additional source of iron oxide to adsorb more As (Rasul et al. 1999). The total cost for developing such a unit is less than US$ 5.

There are, however, a number of unanswered questions about the three pitcher filters that need to be addressed before they are taken up on a larger scale. First, bacteriological contamination of the water occurs before or during filtration. It has not been proven beyond doubt that the water from the three-pitcher filter will be completely free of chemical impurities. The potential for trace elements such as lead, chromium, zinc, tin, etc. to enter the water from the iron filings must be conclusively discounted. The final question about the three-pitcher filter is whether it is technically effective in the long run since it has been observed that after three/four months of continuous use the filters start leaching As. However, the three-pitcher system has enormous potential to provide an emergency drinking water source for the As-affected areas in rural Bangladesh, if the problems mentioned above are taken care of.

4.1.1.6 Activated alumina filter (ALCAN filter)
The basic principle of this system is adsorption of As by activated alumina. In this filter the raw water passes upward through the activated alumina media and the treated water becomes As-free. Activated alumina is formed by the thermal dehydration (250^0C to 1150^0C) of an aluminium hydroxide such as, gibbsite, bayerite, etc. Its principle characteristic is high surface area (>200 m^2/g) and associated porosity. The term activated refers to the capacity of the alumina to enter into adsorption and/or catalytic reactions, and is determined largely by such variables as crystal structure, pore size and distribution, and the chemical nature of the surface.

There are two types of ALCAN systems available: household based units and community-based units. It has been observed in Matlab that household based units are more preferred by people than that of the community-based units.

The activated alumina used as media in the system has to be imported. The initial cost is high for both type of units: US $ 260 per unit (unit + media), and US $ 52 (unit + media) for the household based unit. Running costs are required because the activated alumina needs to be changed periodically. The replacement cost of media for community-based unit is US$140 to treat 80,000 litres of water and for household based unit is US$ 12 to treat 11,000 litres of water. Apart from the cost which seems prohibitive for both individual and community members to replace media on their own, disposal of used material is also another issue of concern not only for Alcan filter but also for all other arsenic removal filters available in Bangladesh. These two issues need to be monitored properly to avoid further hazard.

4.2 Community views about the options

In order to assess peoples' opinions about the provided options, several focus group discussion sessions (FGD) were carried out in different parts of Matlab. The following matrix is prepared based on the information collected using the FGD technique. Table 4 shows the ratings of each of these factors on a scale of 1 to 5. The maximum possible score is 45 and a higher rating indicates more potential.

Table 4. Preference of the alternative safe water options

Parameters	PSF	RWH	Alcan filter	3-pitcher filter	Bishuddha filter	Safi filter
Initial Cost	1	2	2	5	3	2
Running Costs	4	5	1	3	4	3
Ease of implementation	3	3	4	2	4	2
Technical effectiveness	4	3	5	4	4	1
Maintenance required?	4	4	3	2	3	1
Monitoring required?	4	3	2	1	3	1
Continuity of supply	4	2	5	4	4	2
Susceptibility to bacteriological contamination	3	4	4	2	2	3
Social acceptability	5	4	4	2	3	1
Total	32	30	30	25	30	16

From the above exercise, it can be assumed that community preference for PSF was highest among all other available technologies in spite of the few PSFs constructed in Matlab. This small number may indicate the unavailability of ideal ponds required for such construction. On the other hand, it is also true that villagers were not habituated to use PSFs in these areas like people of the coastal belt areas where surface and rainwater harvesters are the only sources for drinking water. It can also be concluded from Table 4 that the rating of PSF, RWH, ALCAN, and Bishuddhya filters were fairly close. In Matlab, when the provided options were assessed to identify a pattern of distribution, interestingly it was observed that the options followed a unique criterion: PSF, where individual or community was found to be ready to sacrifice their earnings from pisciculture and also from other domestic uses; *Bishuddhya* filters, in areas where most of the villagers were found to be still using surface water for drinking and cooking purposes after alum treatment or simply boiling; on the other hand, relative well-off villagers and also the people who do not want to move from using TW water were found to be adopted Alcan filters.

4 CONCLUSIONS AND RECOMMENDATIONS

Supply of As free, safe drinking water remains the most crucial issue in the As mitigation programme. The geohydrological situation of Bangladesh varies from area to area. Similarly, soil types and water chemistry vary from region to region. Water chemistry is particularly important in developing As removal technologies because performance of a number of As removal technologies depends on water quality, especially pH. For immediate safe drinking water supply, short-term options such as As removal technologies can be used. However, to solve the problem permanently, a long-term solution needs to be adopted.

In an area where the proportion of TWs having elevated As concentrations is not high, people can often collect water from the nearby As-safe TWs. Sludge disposal generated from the As removal technologies are an issue of worries. If not disposed of properly, it may have the potential to pollute the surrounding safe ground water again or create a new environmental hazard.

It involved much effort and time to convince people to shift from using relatively polluted surface water to safe ground water. Now people have a strong preference for TW and it would not be easy to shift these large populations from the TW option again. The situation might be worse in areas where no symptoms of arsenic toxicity have become visible even after a long duration of As exposure. Therefore, a strong Behavioural Change Communication (BCC) component should be added with the water supply programmes in order to bring positive changes in the behaviour of the users population.

Before promoting any safe drinking water options, it should be tested at the community level with an adequate sample size because many water options including As removal technologies found to be effective under ideal conditions or at the laboratory may not function properly at the community level. Any water supply options should be assessed in terms of acceptability, affordability and accessibility for the users. The community should bear the responsibility for proper operation and maintenance, without which the water options may rapidly fail. For each water option, caretakers need to be identified from among the users and trained on operation and maintenance issues. Hygiene education is also very important as water may get contaminated not only at the source but also at the distribution, collection and storage point. Another important issue that has not gained adequate importance so far is the health aspect of any given water options. In order to mitigate the As problem, is the water option increasing the risk of any other water borne or water related diseases? Thus risks and benefits analysis of any As mitigation options should be assessed.

Finally, it is clear that the technologies introduced in this project to supply As free safe drinking water are only short-term emergency solutions for areas severely affected by As contamination. The longer-term solutions may include the provision of piped water supply to its population and the optimum use of its surface water.

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