Evaluation of An Arsenic Removal Household Device: Bucket Treatment Unit (BTU)

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INTRODUCTION

The widespread contamination of drinking water by arsenic is a major concern in Bangladesh. Arsenic contamination has been detected in the groundwater of at least 47 districts out of 64 districts in Bangladesh (SOES/DCH, 1998). Arsenic is a known carcinogen and causes cancer. It is also responsible for various lethal physiological problems if taken into the body over the maximum acceptable limit of 0.05 mg/L (set as Bangladesh Standard) for a longer duration. It also creates severe skin related problem creating panic among the common people who regularly consume arsenic laden drinking water. There are around five millions of tube-wells all over the country and more than 95% of the rural population have access to tube-well water. Thus the results of a widespread contamination is likely to be catastrophic. Millions of people are at risk of arsenic contamination, but a significant portion is totally unaware of the danger. Again it is very dangerous because it is impossible to detect the presence of arsenic without special chemical tests. In water arsenic is tasteless, colorless and odorless even at high concentrations. The magnitude of all these complexities of the arsenic problem in Bangladesh makes this an extremely difficult problem to control. Added to all these problems are socioeconomic background of Bangladesh and overwhelming dependence of the people on groundwater.

In Bangladesh, only the major cities of the country are covered by water distribution systems. In the rest areas, mostly in the rural and some small town areas, people use groundwater extracted from their tube-wells located near their households or communities. In view of the overwhelming dependence of the people on groundwater, there is an urgent need to develop a suitable treatment system for removal of arsenic from groundwater. Socio-economic conditions of Bangladesh demands low-cost as well as small treatment units that could be implemented in the rural areas at households or community levels. Again people find it convenient to use household units to treat their arsenic polluted tube-well water, as long as the methods are easy to use and convenient.

Various technologies are available for removing arsenic from groundwater. The most common technologies include: (1) co-precipitation using alum or iron (2) adsorptive filtration (3) ion exchange, and (4) membrane processes like reverse osmosis.

To combat the arsenic crisis, only limited initiatives have been taken for evaluation of existing technologies for removing arsenic from groundwater with small sample size that indicated the need for a systematic and extensive field trial. 'Arsenic Cell' of NGO Forum for Drinking Water Supply and Sanitation evaluated 'Two Bucket' household Unit developed by DPHE-Danida to determine its social acceptability, arsenic removal capacity and assess other water quality parameters of treated water.

Through this research an attempt has been made by the NGO forum to evaluate the Bucket Treatment technology by running 60 units in a village in Manikgonj district, collecting users opinion about the unit and testing arsenic and other water quality parameters in the laboratory.

OBJECTIVES OF THE STUDY

The general objective of the study is to evaluate an arsenic removal household device - 'BTU' (Bucket Treatment Unit), developed by DPHE-Danida. The specific objectives are: (1) To determine arsenic removal capacity of the unit, (2) To determine the iron removal capacity of the unit, (3) To analysis other water quality parameters of treated water such as pH, iron content and bacterial contamination, residual aluminum and residual manganese, (4) To determine the affordability of the unit, (5) To determine the social acceptability of the unit, and (6) To identify the weaknesses of the device and propose solutions.

JUSTIFICATION OF THE STUDY

In this two bucket system, raw water in a 20 litter bucket is coagulated with chemicals containing 4 gm of powdered alum [K_2 (SO_4).Al_2 $(SO_4)_3$..$24H_2O$] and 0.04 gm of powdered potassium permanganate ($KMnO_4$). So according to specification added dose of aluminum is 11.38 mg/L and that of manganese is 0.693 mg/L. According to the WHO, recommended guideline value for drinking water is 0.2 mg/L for aluminum and 0.1 mg/L for manganese. Therefore residual concentrations of aluminum and manganese are of concern. Aluminum is suspected as a neuro-toxic element and many studies show that there is significant relation between excess aluminum in drinking water and Alzheimer diseases. Manganese may have synergistic effect on aluminum toxicity. Besides excess manganese ion imparts undesirable taste to beverages. But alum and potassium permanganate are cheap, stable and easily available in the market.

Again there is a sand filter in this system that needs regular washing, along with other different parts of the unit. So carelessness may promote bacterial contamination of the unit which may pose another health risk to the users. This is an important aspect and needs evaluation.

The evaluation program analyzes arsenic removal efficiency, affordability, social acceptability and robustness of the unit of the unit and assesses other water quality parameters of treated water. This would help develop/modify design criteria for the unit and would also suggest possible alternative effective option.

DESCRIPTION OF BTU

This BTU consists of two 20-liter plastic buckets. The upper bucket is red in color and the lower bucket is green in color. The upper bucket is filled with raw water. Chemical containing 4gm of powdered alum and 0.04 gm of powdered potassium permanganate (according with DPHE-Danida) is added and the water and the water is stirred fast for approximately 25 seconds with a wooden spoon provided with the unit. The water in the red bucket is then overed with a lid and allowed to rest for three hours. The supernatant water is then collected through tap attached to the lower end of the red bucket via a plastic pipe. Micro-flocs, if present in water, can be removed by sand filtration. For this purpose, water collected from upper bucket is passed through a sand filter in the lower green bucket.

The two-bucket system combines different water treatment processes. The first stage of chemical process is pre-oxidation of trivalent arsenic to pentavalent arsenic by the applied oxidant (potassium permanganate), followed by co-precipitation, coagulation and flocculation by applied flocculant (alum); adsorption on flocs; sedimentation; and filtration. The dose of potassium permanganate is 2 mg/L and the dose of alum is 200 mg/L. Coagulation flocculation can also be obtained by ferric chloride/ferric sulfate.

METHODOLOGY

Study Area

Arsenic contamination of groundwater has already been detected in different parts of Ghior, Singair, Harirumpur and Manikganj Thanas of Manikganj district. The study was conducted in the village of Putiajani, Baliakhora Union, Ghoir Thana of Manikganj district about 80 kilometers away from Dhaka. Putiajani village is one of the intervention areas of NGO Forum and its efforts were assisted by local and partner NGO, Socio Economic Development Agency, SEDA. Putiajani is a small village with a population of 1245 with a total household of 250. Total number of tube-well in this village is 76, out of which 65 were found to be functioning at the beginning of the study.

The soil type of Manikganj district is non calcareous gray flood plain soils, calcareous dark gray flood plan soils and calcareous brown flood plain soils, which are prone to have arsenic contamination (BBS, 1997).

Duration of the Study

The evaluation program is planned to be conducted in two phases. The first phase has been completed. The duration of the first phase was from July to December 2000.

Sample Size and Calculation

It has been assumed that the Expected mean arsenic concentration before treatment = 60 ppb; Expected mean arsenic concentration after treatment = 50 ppb; Expected standard deviation = 20; Level of confidence (%) = 95; Power (%) = 80.

So, required sample size is = 52. Considering non-compliance and dropouts, 60 samples were taken. So the sample size was 60. Sample size was calculated using WinEpi software.

Selection of Samples

Initially water samples from 60 tubewells of the study village 'Putiajani' were collected in the prescribed plastic containers and were analyzed for arsenic in the Water Quality Testing Laboratory of NGO Forum using Ag -DDC method. Though Putiajani village has more than 60 tubewells, we couldn't collect samples from all of them as many were in submerged condition due to flood during August 2000.

Out of 60 tubewells, 55 were found to be containing arsenic more than the recommended level of arsenic i.e., 50 ppb. Then the tubewells were divided into 3 divisions according to the arsenic concentration of the tubewells. It was grouped as follows: 50ppb-100ppb, 101-200 ppb and > 201 ppb. Out of 57 tubewells 11 contained arsenic above 201 ppb, 12 contained arsenic between 101ppb and 200ppb and 34 contained arsenic between 50 ppb and 100 ppb.

Out of 11 tubewells containing arsenic above 200 ppb, households using 6 tubewells were excluded as they were using other alternative water options, 10 households using the rest 5 tubewells were included in the study. Out of 12 tubewells containing arsenic ranging from 101 ppb to 200 ppb, 22 families using all these 12 tubewells were included in the study. Out of 34 tubewells containing arsenic ranging from 50 ppb to 100 ppb, 13 tubewells were selected randomly, 28 families were randomly selected from those using these 13 tubewells. Thus a total of 60 households were selected for the study.

Data Collection Procedure

At first water samples of 60 tubewells were collected by the field workers and analyzed in the Water Quality Testing Laboratory (WQTL) of NGO Forum for DWSS. Then 60 households using 30 tubewells were selected for the study. Arsenic concentration of the tubewells ranges from 50 ppb to 580 ppb. After 30, 55, and 78 days of BTU installation, water samples from treated water of all of the 60 households were collected and analyzed for Arsenic, Iron and pH at NGO Forum's Laboratory. After 100 days of BTU installation, samples were collected from all the 60 households for analysis of aluminum, manganese and bacterial population.

Water Sample Collection procedure

Water samples for As, pH, Bacteria (TC-FC) were collected with proper methodology. Sample collection and preservation were also done following required procedure (Tahura, 2001).

Monitoring of BTU

For proper running of the program, monitoring was done through a pre-tested partially open-ended monitoring form.

Social Acceptability

It was examined through focus group discussion (FGD) and in-depth interview.

RESULTS AND DISCUSSION

The presence of arsenic has been detected in groundwater of Bangladesh for at least over the last 8 years. After 8 years of screening tubewells for arsenic, it is clear that this is not the best direction for arsenic mitigation activities. In the absence of any systematic measurement, it is assumed that around 30 million people are at risk of developing arsenic related health hazards through drinking arsenic contaminated water. To save this large endangered population provision of arsenic free safe water is a priority.

Bucket treatment Unit (BTU) is an arsenic removal device developed for household level use. Already many organizations are promoting it. Few small-scale evaluations was made earlier which indicated the need of a systematic field trial of the device to determine arsenic removal efficiency, quality of the treated water, social acceptability and cost-effectiveness of the BTU. Through this study, an attempt has been made to conduct a systematic, extensive field trail of the BTU to evaluate its performance and social acceptability.

The strength of this study is its large sample size, involvement of the community as it is one of the NGO Forum's intervention village, training of BTU caretakers and strong monitoring component of the research.

Household Information

Mean size of the selected 60 household is 5 and sex ratio (M/F) is 0.99. Out of 308 people, 47.4 percent are married. Agriculture, business, and service are the main occupation in the study area. Families having income exceeding the expenditure is 25 percent and mean income of a family is Tk. 3585. About 27 percent families have agricultural land. Only about 12 percent of the families have the pucca and /or semi-pucca houses. 100 percent of the families are using shallow tubewell water. Details of the water use pattern are presented in Table 1.

Information Regarding Tube-well Water

Regarding the location of the tubewells, 65 percent said that they have tubewells in the house premises; the rest of the households were collecting tubewell water from their neighborhood. Out of 34 tubewells only 11.76 percent are government-owned, the rest 88.24 percent are private or owned by NGOs and other private initiatives. The mean age of the tubewells is 9.47 years with wide standard deviation (8.46). Mean depth of the tubewells is 83.82 feet. Minimum depth of the tubewells is 65 feet and maximum is 125 feet. Out of 34 tubewells, 70.6 percent found within the mean depth (85 feet). Fifty percent tubewells had arsenic level between 5-100 ppb and only one tube-well had As level above 500 ppb.

Table 1 : Water use pattern of the household

Sources of water	Purposes of using water									
	Drinking		Cooking		Domestic		Bathing		Agriculture	
	Family	%	Family	%	Family	%	Family	%	Family	%
Shallow TW	60	100	52	86.7	13	21.7	20	20	17	28.33
Pond			4	6.7	2	3.3	20	20		
Canal			1	1.7						
Shallow TW and Pond			3	5	44	73.3	56.7	56.7		
Deep-Well									3	5
Deep well and Dug Well					1	1.7				
Pond and River							1.7	1.7		
Deep well and pond							1.7	1.7		
Total	60	100	60	100	60	100	60	100		33.33

Arsenic in Raw and Treated Water

Table 2 shows arsenic concentration in raw water. Among the 60 samples (from 60 families using 34 tubewells), 29 (i.e., 48.3%) samples contain arsenic between 50 and 100 ppb (SD=14), 21 (i.e., 35%) samples have arsenic between 101 and 200 ppb (SD=32.3), and 10 (i.e., 16.7%) samples contain arsenic above 200 ppb (SD=120.9).

It appears from Table 3 that 55 (i.e., 91.7%) households, 60 (i.e., 100%) households, and 56 (i.e., 93.3%) households have less than 50 ppb after 30 days, 55 days and 78 days, respectively.

Iron Concentration in Raw and Treated Water

Iron concentration has been examined at household level. One third of the households were using tubewell water with iron concentration above 10 ppm, and nearly 50 percent households were using water containing iron between 7 and 10 ppm.

Table 2: Arsenic in Raw Water

As (ppb)	Selected TWs (No)	No. of families selected	Minimum As (ppb) in raw water	Maximum As (ppb) in raw water	Mean As in raw water (ppb)	Std. Deviation
50-100	18	29	50	98	74.167	14
101-200	9	21	109	192	148.89	32.26
>200	7	10	250	580	352.86	122.92
Total	34	60				

Table 3 : Arsenic in treated water

As (ppb)	Treated Water		
	No. of Tubewell after installation		
	30 days	55 days	78 days
<= 50	55(91.67%)	60(100%)	58(96.67)
>50	5(8.33%)	0(0.0)	2(3.33%)
Total	60(100%)	60(100%)	60(100%)

Table 4 shows the basic statistics of iron in raw and treated water. Mean iron concentration in raw water (tube-well water) is 9394 ppb (SD=2931.85, 95% CL=8636.64-10151.39). After 30 days of installation, mean iron conc. of the treated water is 1105.78 ppb (SD= 1466.88, CL=726.93 to 1484.8). After 55 days of installation mean iron concentration of the treated water is 766 ppb (SD=77.59, 95%CL=554.22-977.78). After 78 days of installation, mean iron concentration of the treated water is 1011 ppb (SD=1154.23, 95% CL=712.83-1309.17). Iron concentrations in tube-well water in the DFID study were mostly low (<5 mg/l) and this major difference would appear to account for the more successful behavior of the BTU system in the Ghior Upazila Study.

Aluminum and Manganese Concentration in Treated Water

Dissolves Aluminum concentration in treated water was found to be very satisfactory. Out of the 60 samples 58 (i.e., 96.67%) samples contained dissolved Aluminum less than 200 ppm, the acceptable limit set by Bangladesh Standard (see Table 5). Minimum Aluminum concentration in treated water is 0 and maximum concentration of Aluminum is 680 ppb. The mean concentration of dissolved Aluminum in treated water is 47 ppb (SD=108.91, Median=20, Mode = 20).

Table 4 : Basic statistics of iron concentration in raw and treated water

Description	Range (ppb)		Mean (ppb)	95% Confidence Interval of the Difference		SD	Mean Reduc-tion (%)	Level of signifi-cance
	Min.	Max.		Lower	Upper			
Iron in raw water in ppb	1504	15150	9394	8636.6	10151.4	2932		
Iron in treated water in ppb after 30 days of installation	<30	7459	7459	726.93	1484.80	1467	88	.00
Iron in treated water in ppb after 55 days of installation	<30	3377	766	712.83	977.78	776	91	.00
Iron in treated water in ppb after 78 days of installation	67	4681	1011	712.83	1309.17	1154	89	.00

One of the concerns with BTU is concentration of aluminum in treated water. But in this study, the mean concentration of aluminum is 47 ppb in the treated water, which is within safe limit. Only in case of 2 BTUs, aluminum concentration was found to be above 300 ppb, above the recommended level of 200 ppb set by WHO (WHO, 1993). This study has another component (2nd phase) to follow up health effects, as the role of aluminum is still controversial.

Table 5 : Basic statistics of aluminum and manganese concentration in treated water

Parameter	No of House-hold	Minimum (ppb)	Maximum (ppb)	Mean (ppb)	Median	Mode	Std. Deviation
Aluminum	60	0	680	47	20	20	108.91
Manganese	60	0	1697	703	683	622	370.94

Average Manganese concentration in the treated water was unexpectedly high and above the recommended level of Manganese in drinking water. On our visit to the BTU users after this finding, they were found to be using the chemicals as per as our instructions. So reasons for presence of excess manganese need to be further studied.

Minimum concentration of Manganese ion in treated water was 0 ppb and maximum concentration was 1697 ppb, mean concentration was 703 ppb (Median=683 ppb, Mode = 622 ppb, SD =370.94). Only 2 (i.e., 3.33%) samples out of 60 contained Manganese less than or equal to 100 ppb, the Bangladesh drinking water standard. Five percent, 5 percent, 6.67percent, 10 percent, 50 percent, 20 percent of samples contained 101-200, 201-300,301-400,401-500,501-1000 and >1000 ppb of dissolved Manganese, respectively, in treated water (see Tables 5 and 7).

Table 6 : Aluminum in treated water

Aluminum	No of Samples	Percent
<=200ppb	58	96.67
>=200 ppb	2	3.33
Total	60	100

Table 7 : Manganese in treated water

Manganese	No of samples	Percent
<=100ppb	2	3.33
101-200ppb	3	5
201-300ppb	3	5
301-400ppb	4	6.67
401-500ppb	6	10
501-1000ppb	30	50
>1000 ppb	12	20
Total	60	100

Bacterial Contamination of treated water

Tables 8 and 9 show the bacterial contamination in treated water.

Table 8 : Basic statistics of bacterial concentration in treated water

Description	No of samples	Minimum	Maximum	Mean	Std. Deviation
Total coliform (#/100 ml) in treated water after 100 days of installation	60	0	1600	286	5.94
Faecal coliform (#/100ml) in treated water after 100 days of installation.	60	0	1600	66	241.63

Table 9: Concentration of Coliform (TC) group

TC group #/100 ml	Total Coliform (TC)		Faecal Coliform (FC)	
	# of Sample	Percent	# of Sample	Percent
0	8	13.3	26	43.33
1-100	33	55	27	45
101-250	7	11.7	4	6.67
251-500	2	3.33	1	1.67
501-1000	2	3.33	1	1.67
>1000	8	13.3	1	1.67
Total	60	100	60	100

Mean concentration of total coliform of treated water was 286 (± 6) and that of faecal coliform was 66 (±242). In 8 (i.e., 13.33%) BTUs there were no TC and in 26 (43.33%) BTUs there were no FC. 55, 11.67, 3.33, 3.33 and 13.33 percent of samples contained 1-100, 101-250, 251-500, 501-1000 and >1000 unit (#/100 ml) TC, respectively (Table 8); and 45, 6.67, 1.67, 1.67 and 1.67 percent of samples contained 1-100, 101-250, 251-500, 501-1000 and >1000 unit (#/100 ml) FC (Table 9), respectively.

pH Values of Raw and Treated Water

The pH values of the BTU treated water samples were tested in this study and pH was found to marginally decrease following the addition of the aluminum sulphate coagulant. A total of 11 samples were tested for pH. Minimum pH in raw water is 6.65 and the maximum value of pH in raw water is 8.25. The mean concentration of pH is 7.35 (± .4361). Mean pH of 11 samples of treated water was 7.21 (± .4906). Minimum value of pH in treated water was 6.4 and the maximum value was 8.02 (Table 10).

Table 10: pH of raw and treated water

Description	No of samples tested	Minimum	Maximum	Mean	Standard Deviation
pH in raw water	11	6.65	8.25	7.35	.4361
pH in treated water	11	6.4	8.08	7.21	.4906

RECOMMENDATIONS

Based on the quantitative and qualitative (FGD and In-depth study) information derived from this study, the following recommendations have been made:

(1) BTU can be used as an arsenic removal device at household level if it fulfills the basic criteria.
(2) The BTU should be stronger structurally. The quality of the buckets should be improved.
(3) Arsenic contaminated water should be allowed to stand for more than 3 hours until the coagulated flocs settle down the red bucket and upper water of red bucket looks crystal color.
(4) Given the discrepancies in different study results, BTU can be promoted where the water iron content is high.
(5) Alternative water options for arsenic mitigation should be region-specific, based on the water criteria of the areas. Area-specific characteristics of water should be known or attempt should be made to know it.
(6) Iron salt [$FeCl_3/Fe(SO_4)_3$] may be used instead of Alum to avoid controversy.
(7) BTU should be promoted if the arsenic concentration of the raw water is within 500 ppb.
(8) BTU should not be promoted in any community on large scale without strong monitoring support.
(9) At least 1 female caretaker should be trained from each household using BTU.
(10) BTU chemicals should be made available locally.

(11) The sand used in the filter column should be strictly coarse sand retained on #30 mesh (DPHE/Danida, 1999).
(12) The proportion of alum and potassium permanganate should be strictly maintained as per suggestion and chemicals should be supplied in selected condition.
(13) Sand should be washed and boiled with water after every 15 days.
(14) Awareness should be built up in the community before they are provided with BTUs

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