Bangladesh Environmental Technology Verification - Support to Arsenic Mitigation (BETV-SAM)

FIELD TESTING AND PERFORMANCE EVALUATION

OF

NELIMA HOUSEHOLD ARSENIC REMOVAL TECHNOLOGY

November 2009

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1. Introduction

Nelima Household Arsenic Removal Technology (Nelima HART) has been tested in five hydrogeologically different areas of Bangladesh. This verification report summarizes the results of field tests of this technology for drinking water supply at the household level. The field tests were conducted following Nelima Technology Specific Test Plan (TSTP) and other pertinent protocols as described in the Bangladesh Environmental Technology Verification – Support to Arsenic Mitigation (BETV-SAM) program and approved by BCSIR.

The field tests have been conducted on five wells in Dohar, Chandina, Begumgonj, Ishwardi, and Chapai over a period of up to six and half (6.5) months. The wells were chosen on the basis of arsenic, iron and phosphate ion concentrations and cover a range of concentrations from low values up to, or close to, the values that the proponent claimed its technology can handle. The water quality parameters, therefore, provided a rigorous basis for verification of the proponent's performance claim.

This Verification Report presents and analyses the field test data and provides the Verification Statements for Nelima ART. The analysis of field data, primarily arsenic, iron and phosphate concentrations and solution pH in raw and treated water was carried out employing MINITAB14[1] statistical software. Analysis of other water quality parameters was also accomplished using statistical analysis when possible or by both simple data observation and chemical principles.

2. Technology Description and Field Testing Procedures

Nelima ART is a batch flow technology and consists of a pair of plastic buckets, each approximately 30 L in volume, placed one (red bucket) above the other (green bucket) on a folding tripod steel stand and an iron and an arsenic removal filter cartridges. The iron and arsenic removal filter cartridges are placed vertically and in separate holders located outside of the lower bucket as shown in figure 2.1. The top bucket is perforated along the brim for aeration. It is fitted with a water stopper few centimeters above the bottom of the bucket in order to prevent the flow of settled sludge out of the bucket and into the sand filter cartridge.

[1] Minitab Inc., USA Office, Tel:1-814-238-3280, Fax: 1-814-238-4383

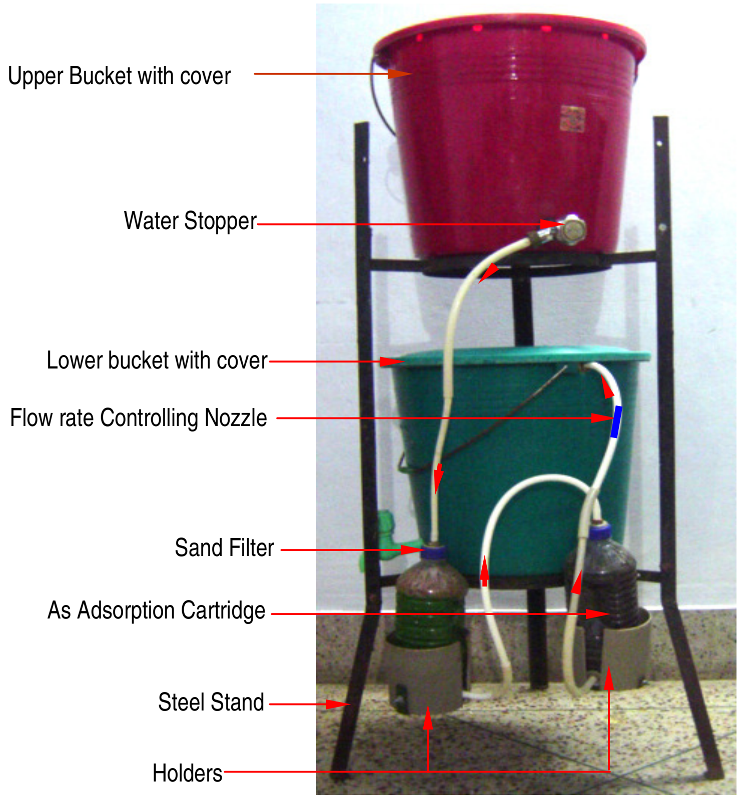

Figure 2.1: Modified Nelima Arsenic removal Unit

The two buckets and the filter cartridges are connected to each other by flexible tubing. The arsenic contaminated well water is added to the top bucket and aerated, through stirring, to speed-up the oxidation and flocculation of dissolved iron. The water is then allowed to stand for a period of thirty minutes to two hours, depending on the concentration of dissolved iron in the groundwater, to allow dissolved iron oxidize, coagulate and precipitate. Then the water tap attached to the bucket is opened to let the water to pass through the sand and arsenic removal cartridges and collect in the green bucket. The former removes coagulated iron hydroxides and the later adsorbs arsenic dissolved in well water. The technology is designed to serve a single household and can produce up to75 liters of arsenic-safe water in a day.

The field testing was conducted over a period of about 160 to 180 days. During the field testing period, samples of raw and treated water were collected at regular intervals and analysed for different water quality parameters as described in the TSTP.

3. Proponent's Technology Performance Claim

The proponent claims that a Nelima ART unit is capable of producing approximately 8100 L of arsenic-safe water from influent water that ranges in pH from 5.5 to 8.0, and contains As, Fe and PO_4^{3-} at concentrations of up to 350 μg/L, 10 mg/L and 4 mg/L, respectively. The proponent also claims that the technology is designed to produce, at the minimum, 75 L of arsenic-safe water for a single household.

4. Verified Performance Statement

4.1 Seven units of Nelima ART has been field tested on five wells in five different locations; three single units were installed and tested on three wells – one unit per well per region – in Ishwardi, Dohar and Chandina and two sets of duplicate units were installed and tested on two wells in Chapai and Begumgonj. A summary of the well water quality parameters along with their corresponding 95% CI (confidence intervals) is provided in **Table1**. The well water quality parameters satisfy – for the most part – those that were specified by the proponents for the most part.

4.2 The field tests measured the flow rate, the volume of water that can be treated by the technology in approximately eight (8) hours period in a day and the cumulative volume of arsenic-safe water produced during the testing period.

4.3 During the field testing, raw and treated water samples have been collected at regular intervals and analysed for concentrations of dissolved arsenate and arsenite, iron, phosphate and other water quality parameters. Between 80 and 90 percent of arsenic present in well waters were As(III).

4.4 Figure 1 shows plots of effluent arsenic concentrations as a function of cumulative volume of arsenic-safe water produced by the technology. The effluent arsenic data has been analyzed statistically using t-statistic[2] and the result of this analysis shows that:

A) The data appears to be randomly distributed around a mean value,

[2] The ***t-statistic***, discovered by W. G. Gosset in 1908, is employed when number of samples to be analyzed is small, the normal distribution of the sample mean may not be applicable and the sample standard deviation is different from the true population standard deviation (obtained for a large number of samples).

B) The mean effluent arsenic concentration is much less than 50 µg/L with 95% confidence, and

C) There is no evidence of eminent arsenic breakthrough.

4.5 The volume of arsenic-safe water produced by each unit and the mean concentrations of arsenic in the treated water are presented in **Table 2**. The technology could have produced more arsenic-safe water had the testing continued for longer period of time.

4.6 The data presented in **Table 2** clearly demonstrate that Nelima ART was able to meet and exceed the proponent's performance claim in all sites.

4.7 Replicate units were tested on two well and the results presented in **Table 2** show that replicate units installed on the same wells also produced arsenic-safe water from a given water matrix, which indicates the uniformity and reproducibility of the technology manufacturing process.

Table 1: Summary of the well water quality parameters

Location and Well Number	[As]/µg/L Mean ± CI[3]	$[As(III)]/[As]_T$	$[Fe^{+2}]$/mg/L Mean ± CI	$[PO_4^{3-}]$/mg/L Mean ± CI	pH Mean ± CI
Begumgonj/W30	352 ± 37	0.9	4.15 ± 0.95	4.05 ± 0.25	7.3 ± 0.1
Chandina/W57	172 ± 14	0.9	15.57 ± 1.82	3.10 ± 1.38	7.1 ± 0.0
Chapai/W16	241± 66	0.9	0.93 ± 0.49	0.28 ± 0.14	6.8 ± 0.1
Dohar/W57	299 ± 33	0.9	3.85 ± 1.08	2.10 ± 0.30	7.1 ± 0.1
Ishwardi/W93	371 ± 139	0.8	3.76 ± 0.31	0.72 ± 0.183	7.0 ± 0.1

[3] CI is Confidence Interval; Mean ± CI shows 95% confidence intervals

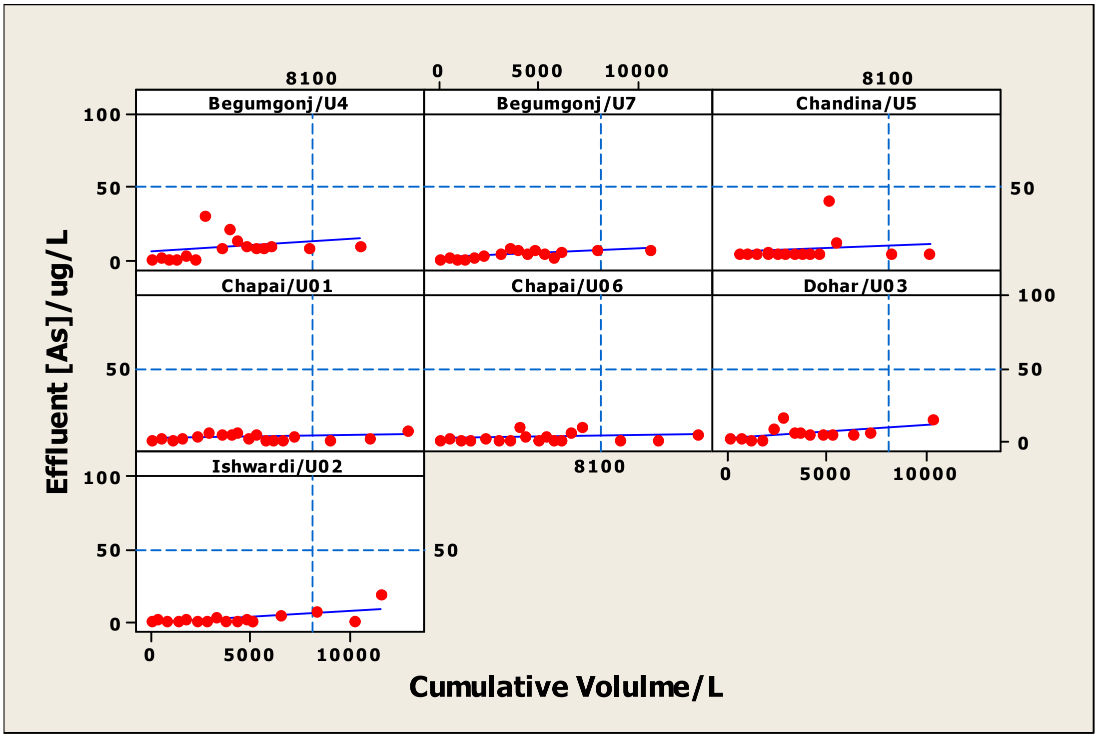

Figure 1: Plots showing Effluent As Concentration vs. Cumulative Volume of Treated Water

Table 2: Summary of statistical analysis (***t-statistic***) of arsenic concentrations in Nelima ART treated water samples, prior to breakthrough, in different locations

Location/ Unit	N[4]	Mean effluent [As] ± CI/ µg/L	Vol. of Potable Water Produced	Proponents Claim	Verification of Performance
Begumgonj/U4	16	9 ± 4	≥10590	8100	Verified
Begumgonj/U7	16	4 ± 1	≥10590	8100	Verified
Chandina/U5	15	8 ± 5	≥10150	8100	Verified
Chapai/U01	18	3 ± 1	≥12980	8100	Verified
Chapai/U06	18	3 ± 1	≥12980	8100	Verified
Dohar/U03	14	6 ± 2	≥11680	8100	Verified
Ishwardi/U02	17	3 ± 2	≥10250	8100	Verified

[4] Number of data points used for statistical analysis

5. Evaluation of Additional Technology Performance Characteristics

In addition to analyzing raw and treated water for arsenic concentrations and other water quality parameters reported in the above section, the water samples were also analysed for a host of other natural as well as technology-specific inorganic ions and bacteriological contaminations. The BETV-SAM field testing program has also characterised arsenic wastes generated during the testing period for their toxicity. These findings have important implications for the technology performance, the quality of water it generates, and the handling and disposal of the wastes that are produced.

1. *Daily Production Capacity*: The volume of water that can be treated in a day by the technology is about 75 L, which is in complete agreement with the proponent's claim.
2. *Removal of other Chemicals*: The raw and treated water samples have been analyzed for manganese and other dissolved metal ions. Wells selected at all five testing sites contain manganese at concentrations above the WHO drinking water guidelines of 0.4 mg/L. **Figure 2** shows plots of effluent Mn concentrations as a function of cumulative volume of treated water. As can be seen, the concentration of Mn in the treated water increases with increasing cumulative volume of treated water and reaches to a plateau. The data presented in **Figure 2** clearly indicating that Nelima ART has limited capacity for manganese and that the manganese removal efficiency decreases gradually with increasing volume of treated water. Furthermore, the data presented in **Figure 2** clearly demonstrate Nelima ART cannot treat groundwater containing ≥ 0.4 mg/L of manganese and continually generate treated water with acceptable level of manganese.
3. *Technology Added Chemicals*: Analysis of raw and treated water samples show that the Nelima ART does not add any chemical to the treated water.
4. *Bacteriological Contamination*: Samples of raw and treated water have been analysed for thermotolerant bacteria (TTC) and *E.coli*. The test results, presented in **Table 3**, show that:
    - A. The well waters are free from bacteriological contaminations.
    - B. Most of the treated water samples were contaminated with low level of TTC and a few were also contaminated with *E.coli*. However, one sample was found to be contaminated with high level of both the TTC and *E.coli*.

C. The observed bacterial contaminations are most likely introduced by the technology operators.

D. The data trend does not indicate that the Nelima ART foster the growth of biological contaminations. The growth found can be related to secondary contamination.

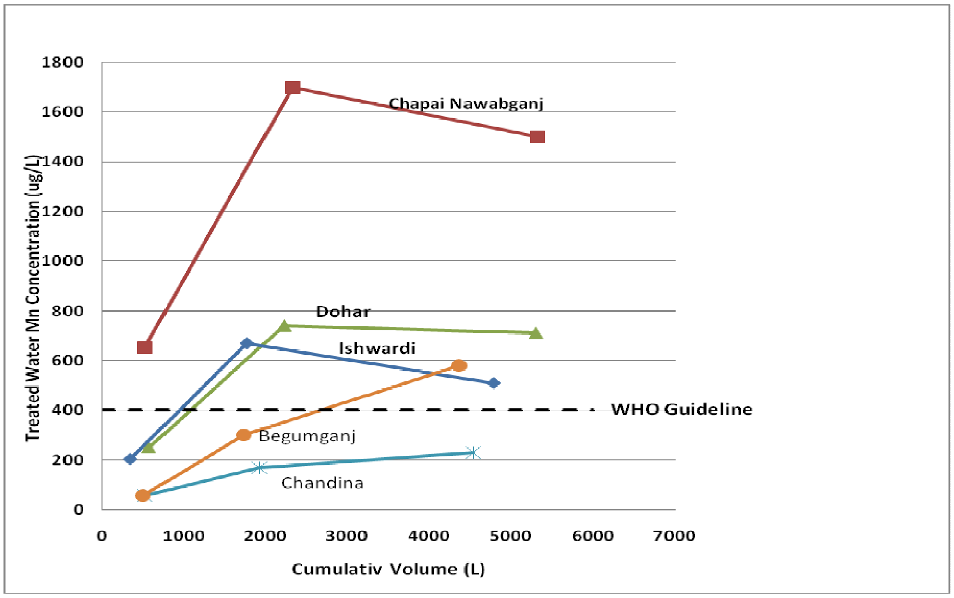

Figure 2: Plots showing Effluent Mn Concentration vs. Cumulative Volume of Treated Water

Table 3: Bacteriological analysis data for the raw and treated water

Location/Unit	Sampling Date	Influent		Effluent	
		TTC	E. coli	TTC	E. coli
Dohar/U3	24 December 08	0		0	
Dohar/U3	25 January 09	0		8	2
Dohar/U3	15 March 09	0		5	0
Dohar/U3	01 April 09	0		3	0
Dohar/U3	29 April 09	0		3	0
Dohar/Blank	15 March 09			0	
Chandina/U5	19 January 09	0		0	
Chandina/U5	08 February 09	0		0	
Chandina/U5	02 March 09	0		2	2
Chandina/U5	22 March 09	0		3	0
Chandina/U5	13 April	0		6	9
Chandina/Blank	02 March 09			0	
Ishwardi/U2	01 December 08	0		7	3
Ishwardi/U2	31 December 08	0		0	
Ishwardi/U2	26 January 09	0		638	319
Ishwardi/U2	16 February 09	0		0	
Ishwardi/U2	09 March 09	0		2	0
Ishwardi/Blank	26 January 09			0	

6 Waste Characterization

The sludge generated by the Nelima ART in two sites along with arsenic removal media and sands from those unites – one with the highest arsenic and one with the low arsenic in well water – were characterized for toxicity following Toxicity Characteristic Leaching Procedure (TCLP) and Total Available Leaching Procedure (TALP) tests procedure. These tests were conducted on a homogeneous sample of the sludge, the sand filter and the arsenic media obtained from units tested in Chapai and Ishwardi as described in the TSTP. Arsenic contents of filter media, the iron sludge and extracts were measured by AAS. The TCLP and TALP extracts were also sent for metal scan for analysis of concentrations of other regulated metals and those data are not available at this time.

Analytical data from TCLP and TALP characterizations are presented in **Table 4**. As expected, arsenic accumulated on iron removal is proportional to the arsenic level in well water and the arsenic contents of the sludge and sands from the sand filter are very low. Furthermore, the leaching characteristics of the iron sludge, the arsenic removal media and the sand as determined by the TCLP and TALP tests (see **Table 4)** clearly show that they can be classified as non-hazardous materials. This is because a waste is characterized as hazardous if the concentration of arsenic in the extract is more than 5.0 mg/L and the concentrations of arsenic found in the extract solutions are far below this regulatory limit.

Table 4: Arsenic content of the Iron sludge, the filter media and leachates

Location	Sample	Arsenic content (mg/Kg)	Arsenic leaching from media	
			TCLP (µg/L)	TALP (µg/L)
Chapai	Iron Sludge	4404	232	492
	GFH media	83	31	64
	Sand	157	17	262
Ishwardi	Iron Sludge	2682	332	507
	GFH media	17	28	24
	Sand	183	846	147

7. Recommendations and Deployment Conditions for Nelima ART

The field test data presented and analyzed in previous sections indicate that Nelima ART can produce arsenic-safe water if it is deployed on wells that meet the deployment conditions specified below and operated following the procedures described in this report. The data also show that the treated water can be contaminated with biological contaminations if the technology operators do not wash their hands, clean water collection containers, and do not practice appropriate hygiene. The also show that the technology does not harbour or grow bacteria. It is for these reasons that BCSIR makes the following recommendations and deployment conditions for Nelima ART.

7.1 Recommendations

Seven units of Nelima ART have been deployed and installed on 5 wells – two Duplicate units were installed on two wells - in five different regions of Bangladesh and operated by the field testing agencies under the supervision of the BCSIR Verification Unit scientists. The data presented in the previous section show that:

1. All units performed well and there were no signs and/or indications that any of the units were nearing the end of media useful life during the field testing period (see Figure 1).
2. The technology generated between 10,590L and 12,960 L of arsenic-safe water.
3. The performance of Nelima ART exceeded the proponent's performance claim.

The technology can provide arsenic-safe water to people in arsenic affected areas of Bangladesh by following the deployment conditions specified below. Therefore, it is recommended that Nelima ART be certified for marketing and sale in Bangladesh.

7.2 Deployment conditions

The field test data presented in previous sections show that Nelima ART can produce arsenic-safe water if it is deployed on wells that meet the conditions specified below and operated following procedures specified in this report. Moreover, the treated water can be protected from biological contaminations if operators practice appropriate hygiene.

7.2.1 Deployment Conditions

Nelima ART can produce arsenic-safe safe water if it is installed on wells that meets the following conditions and operated by following the instructions given in this report.

1. The technology was found to be able to produce arsenic-safe water from well waters contaminated with [Arsenic] ≤ 400 μg/L, [Iron] ≤ 13.0 mg/L, [Phosphate] ≤ 4.0 mg/L, and pH ≤ 7.3.
2. The technology cannot continuously remove manganese from well water. Therefore, it should not under any circumstances be deployed on wells contaminated with greater than 0.4 mg/L of manganese.
3. The well water should be analyzed before the deployment and installation of a Nelima unit to make sure that well water meets conditions specified in sections **7.2.1.1** and **7.2.1.2** above.
4. The proponent must supply an *Installation, Operation and Maintenance Manual* that contains the **RECOMMENDATIONS AND DEPLOYMENT CONDITIONS FOR NELIMA** (**Section 7**).
5. Well water should be poured into the top (red) bucket, mixed well with the mixer to saturate it with air, allow the water to stand in the bucket for 30 minutes if well

water iron is less than 2 mg/L, an hour if it is between 2 to 4 mg/L, and 2 hours if it is more than 4 mg/L for iron to oxidize, flocculate and precipitate out. The water is then allowed to it pass through sand and arsenic removal filters and collect in the lower (green) bucket.

6. The technology performance should be monitored after deployment to make sure that treated water is safe for human consumption. Therefore, treated water should be tested for arsenic immediately after technology installation.
7. The water quality of at least 5% of the wells selected for the technology deployment under the conditions stated in **7.2.1.1** and **7.2.1.2** above should be analysed at BCSIR analytical research division laboratory or any other qualified analytical laboratories in order to be able to verify deployment conditions.
8. The technology proponent must comply with the National Waste Management Protocol approved by the Government of Bangladesh regarding safe disposal of the waste generated by technologies.

The technology proponent must supply an Installation, Operation and Maintenance Manual to end users that incorporates the directives given in the Recommendations and Deployment Conditions for Nelima ART section and the operating conditions specified in this report and must train at least one person to be responsible for technology operation and maintenance.

7.2.2 Backwashing and Media Replacement

The technology works best and produces arsenic-safe water if it is operated and maintained well and arsenic removal media is replaced on-time.

1. The technology performance should be monitored periodically to ensure that treated water is arsenic-safe. Hence, the treated water should be tested for arsenic after six month and once a month thereafter that.
2. The arsenic removal media should be replaced when arsenic concentration in the treated water is greater than 40 µg/L.
3. The sand and arsenic removal cartridges should be backwashed and the buckets should be washed once every 5 days when dissolve iron concentration in well water is ≤ 2 mg/L and every 2 days when dissolve iron concentration is > 2 mg/L to remove sludge's accumulated in the filters and in the buckets.

4. The backwash water should be stored for a day, the supernatant separated and discarded afterwards, and the sludge should be collected and disposed, by the technology proponent/provider, following the conditions stated in 6.5 above.
5. A Nelima unit that is deployed following the above conditions to serve a single family should be able to produce arsenic-safe water for at least one year at a rate of 45L/day. Therefore, the arsenic removal cartridge have to be replaced with a new one after – at most – once a year, if treated water cannot been tested to ensure that arsenic concentration in the treated water is below 50 µg/L and conforms to the Bangladesh drinking water standard for arsenic. This is a costly option; however, it is the only option that would lower the villager's risk of consuming water contaminated with unacceptable level of arsenic, due to the fact that the Nelima unit's arsenic removal cartridge has possibly reached the end of its useful life.

7.2.2 Hygiene Practices

Treated water from Nelima ART can be contaminated with bacteria if operators do not practice appropriate hygiene or disinfect sand filter, and buckets, Kolshis, and pots used to collect well water and store treated water are not cleaned and disinfected before collecting water. It is important that:

1. The end-users wash their hands with soap and plenty of water and make sure that they are absolutely clean before attempting to operate the unit.

2. The pots and pans used to collect and store well water and/or treated water should be washed, cleaned and disinfected before use. To do this, add about 2 L of water to the bucket (or Kolshi if one is used), add one tea-spoon of either Chlotech solution or half a teaspoon of bleach powder to the water, mix it well, swirl it around a number of times and use it disinfect other buckets/Kolshis or throw it away, and finally rinse these buckets/Kolshis with clean water.

4. The sand filter should be disinfect at least once in a week and after backwashing by adding a solution of sodium hypochlorite containing half a tea spoon of bleaching powder in a liter of water into the filter and allowing it stand for about 10 min. Then empty the filter and wash the sand filter thoroughly with treated water for two to three times.

7.2.3 Technology Users Support Systems

This section deals with the support system for the technology user. Nelima ART certification is not based on the realization of the recommendations made here. The BETV-SAM, however, feels that efforts should be made to fulfil the following recommendations and that they are essential to the sustainable use of Nelima ART.

1. *Analysis of treated Water for Arsenic*: As suggested above, Nelima technology users should replace the Nelima unit after 1 year, unless they can have water treated by their Nelima unit and know that after one year, the unit is still producing arsenic-safe water. Ideally, however, a mechanism should exist that would allow testing the treated water affordably at regular intervals before the one year time line is over, to ensure that the unit is still functioning properly and producing arsenic-safe water for the household that acquired the unit. This would provide the most reliable indicator of when the Nelima unit in a possession stop producing arsenic-safe water and needs to be replaced with a new unit. This test would consist of an analysis, using a reliable laboratory or a reliable field test kit used by a trained technician, of the arsenic concentration in the treated water. Presently, there are very few facilities in the arsenic affected areas of Bangladesh that have the ability to analyse water samples for arsenic with acceptable and consistent level of accuracy. Such facilities are required if ARTs are to be used in an optimal manner, from the standpoint of producing arsenic-safe water. There are DPHE and NGO regional laboratories/offices that should be able to provide such a service. In addition, there are trained community healthcare professionals and possibly young university graduate entrepreneurs, who would be able to provide this service with training and assistance from DPHE, BCSIR, and other governmental organizations. It is the role of DPHE to promote and over see the development of a testing capability in arsenic-affected areas.
2. ***Technology Distribution System:*** Any technology may break down at some point in its life. Repairs and spare parts will be needed. This and other investigations have found that taps, buckets, and other pieces of a Nelima break down often enough and have to be replaced. For most households, reaching the Nelima vendor and acquiring replacement would be very, very difficult if not impossible altogether. A distribution office in the vicinity, a store acting as an agent for the vendor, or any such facilities located in the town shopping centre or within a convenient distance would be very useful. If these facilities were available in the immediate vicinity, then Nelima ART users could readily obtain parts required for repairing a broken unit, ask questions about technology operation and

maintenance, and obtain guidance if and when needed. Furthermore, Nelima ought and should stock-up spare parts and supply them to distribution offices, vendors, etc.