

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

**PERFORMANCE MONITORING AND
EVALUATION**

OF

SONO 45-25 Arsenic Removal Technology

Final Performance Verification Report

October 2009

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ACRONYMS

ART	Arsenic removal technology
BCSIR	Bangladesh Council of Scientific and Industrial Research
BDW Std	Bangladesh Drinking Water Standard
BETV-SAM	Bangladesh Environmental Technology Verification – Support to Arsenic Mitigation
BGS	British Geological Survey
ETV-AM	Environmental Technology Verification – Arsenic Mitigation
GoB	Government of Bangladesh
MA	TPM Monitoring Agency
NAMIC	National Arsenic Mitigation Information Centre
TEC	Technical Expert Committee
TPM	Technology Performance Monitoring
TTC	Thermotolerant Coliform
WHO	World Health Organization

EXECUTIVE SUMMARY

The Bangladesh Environmental Technology Verification-Support to Arsenic Mitigation (BETV-SAM) project is a bilateral project between the Governments of Bangladesh and Canada. The project, among other activities, field tests arsenic removal technologies (ARTs) in order to either verify or deny a technology performance claim. The Environmental Technology Verification-Arsenic Mitigation (ETV-AM) project, predecessor to the BETV-SAM project, had selected and field tested five ARTs; four technologies, including Sono, have been provisionally verified and are allowed to be marketed for normal household and community use, under the Conditions of Deployment specified in the provisional certificate document. Full certification of these technologies depends on their long-term performance during the Technology Performance Monitoring (TPM) Program.

The TPM Program was designed to assess the performance of provisionally verified ARTs under “real world” conditions, over a period of one year. The Program deployed thirty one (31) units of Sono 45-25 household (Sono) ARTs over twenty five (25) wells with 25 different water matrices in Manikganj, Balagonj, Jhikargacha, Bera and Chapai. These areas were chosen on the basis of their groundwater quality parameters, e.g. arsenic, iron and phosphate concentrations that meet or exceed the deployment conditions set in the provisional verification for these particular ARTs. Wells were selected following site selection criteria and the deployment conditions including suitability of water matrix, ease of access, proximity to possible point sources of pollution, and availability of space for installing ART, storing equipment, and performing water analysis on site.

Sono ART units were operated and maintained by end-users, who were trained by the technology proponent and the monitoring agency’s (MA) field crews and supervised by the latter. They recorded the volume of water treated in a day, assisted MA field crews in their routine work, and participated in other housekeeping activities.

The technology performance was closely monitored by the MA field crews; who analyzed treated water for arsenic on a weekly basis using Arsenators by following strict

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QA/QC protocols; and collected samples of raw and treated water at regular intervals and delivered these to designated laboratories to be analyzed for arsenic, other chemicals, and microbiological contamination. The program lasted for about twelve (12) to fourteen (14) months to collect adequate data to be able to assess the performance of the Sono ART.

The data collected during the TPM program demonstrates that the technology performs much better than it did during the ETV-AM program. Only one Sono unit reached breakthrough point after generating about 23,100 L of arsenic-safe¹ water; the other units were not even on the verge of breakthrough after producing more than about 22,000 L of potable water and were producing arsenic-safe water when the field monitoring was terminated.

Analysis of data presented in this report lead to the following conclusions.

1. The technology can produce arsenic-safe water that meets Bangladesh drinking water standard guidelines from well water contaminated with $\leq 1200 \mu\text{g/L}$ of As, $\leq 9.0 \text{ mg/L}$ of phosphate, $\leq 1.5 \text{ mg/L}$ of manganese, $0.0 - 13.0 \text{ mg/L}$ of iron, and $\text{pH } 7.0 \pm 1.0$.
2. A Sono unit, installed and operated following the above instructions, should be able to provide arsenic-safe water to a single family, 45 L to 50 L per day, for at least two years and generate $\geq 32,000 \text{ L}$ of arsenic-safe water.
3. The technology performance should be monitored regularly to make sure that treated water meets the Bangladesh drinking water standards.
4. The Sono ART can and should be certified, with revised deployment conditions presented in **Section 5.2**, for marketing and sale in Bangladesh.

¹ "Arsenic-safe" is a terminology used to indicate that total As $< 50 \mu\text{g/L}$, i.e. below the permissible value for drinking water standard in Bangladesh (Government of Bangladesh: Ministry of Environment and Forest (1997) Environment Conservation Rules: Schedule 3.)

1. INTRODUCTION

The Bangladesh Environmental Technology Verification-Support to Arsenic Mitigation (BETV-SAM) project is a bilateral project between the Governments of Bangladesh and Canada. The project, among other activities, field tests arsenic removal technologies (ARTs) in order to either verify or deny a technology performance claim. The Environmental Technology Verification-Arsenic Mitigation (ETV-AM) project, predecessor to the BETV-SAM project, had selected and field tested five ARTs. BCSIR, on the basis of the field test results and recommendations from the Technical Expert Committee (TEC)², has issued Provisional Verification Certificates to four (4) technologies, Alcan, Read-F, Sidko, and SONO ARTs. These technologies are allowed to be marketed in Bangladesh to treat arsenic-contaminated groundwater under conditions stipulated in the Legal Agreement that the proponents signed. In addition, the ETV-AM program recommended an expanded field monitoring program, which examines the performance of these technologies in other regions and with different water quality parameters with the aim and/or hope of constructing a more complete picture of the capabilities and limitations of these technologies in Bangladesh.

The BETV-SAM Field Technical Performance Monitoring (TPM) Program was designed to assess the long term performance of these four ARTs under “real world” conditions and to generate data that will show the true capabilities of these technologies. Each technology that performs satisfactorily under this program will receive a final verification certificate from BCSIR. If on the basis of the TPM results, it is deemed necessary the existing deployment conditions for the technology should be modified; the modifications will be documented in the deployment conditions provided with the final Verification Certificate.

This program deployed thirty one (31) units of Sono ART, a photograph of which is shown in **Figure 1**, over twenty five (25) wells with 25 water matrices in Manikgonj,

² The TEC is composed of a select group of scientists and technology experts, assembled to advise BETV-SAM on technical aspects of the project.

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Balagonj, Jhikargacha, Bera and Chapainawabgonj regions of Bangladesh. The program closely monitored the performance of these Sono units for about more than one year. The results of the year long TPM program on the Sono ART are presented and discussed briefly in this report.



FIGURE 1: A photograph of Sono ART

2. OBJECTIVE

The primary objective of the TPM program was to field test the Sono ART in different regions of Bangladesh under “real world” conditions and:

- A. Assess its performance by collecting raw and treated water samples and analyze them for arsenic (As), other chemicals, and microbial contamination,
- B. Improve the technology’s performance and output, if possible, through modification of Operation and Maintenance procedures,
- C. Determine well water quality parameters, i.e. concentrations of arsenic, iron, phosphate, manganese, pH, etc. that the technology can treat , and produce potable/safe water
- D. Make sure that treated water meets Bangladesh drinking water standard or WHO drinking water guidelines.

The project would, based on the TPM observations, either accept or reject the Sono proponent’s performance claim³. If the technology performance is verified at the end of the TPM project, the technology would be recommended for certification by the Government of Bangladesh (GoB) and be allowed to be marketed in Bangladesh under the set conditions that would be specified in the technology verification certificate.

³ Limitations of Performance Verification Statements and Range of Applicability – Verification applies only to the operating conditions stated in the performance verification statement. In the monitoring program, the verification applies to the individual technology operated under the conditions of the verification test at the individual well.

3. PERFORMANCE MONITORING PROCEDURES

A detailed description of the technology performance claim, working and deployment conditions, and performance monitoring procedures have been described in detail in the Field Monitoring Instructions and Handouts and will only be described briefly in the following sections.

3.1 TECHNOLOGY DESCRIPTION

The Sono- ART – a schematic of which is shown in Figure 2 – is a two-stage arsenic removal filter and is designed for a single household. It consists of two covered buckets placed one over another in an iron base rack. Each bucket is fitted near the bottom with a valve to control water flow. The top bucket is red in color and is packed with brick chips, coarse sands, and iron casting. The bottom bucket is green in color and is packed with brick chips, coarse and fine sands, and charcoals. The former is packed from the bottom with separate layers of brick chips (around the tap), coarse sands, iron composite materials and coarse sand and the latter is packed from the bottom with separate layers of brick chips (around the tap), coarse sands, charcoals and coarse sands. The different layers in each bucket are separated by a sheet of polyester mesh and the two buckets are connected to each other by flexible tubing. To operate the technology, 22-25 L of well water is poured into the top bucket and treated water is collected from the bottom bucket. The technology should not be used to generate more than 57 L of arsenic-safe water in a day.

3.2 PROPONENT'S PERFORMANCE CLAIM

The proponent originally claimed that the SONO ART is able to treat groundwater contaminated with ≤ 750 $\mu\text{g/L}$ arsenic and produce 74,460 L of arsenic-safe water at a minimum flow rate of 17 L/hour. The ETV-AM program, on the other hand, specified that the technology could treat groundwater contaminated with ≤ 750 $\mu\text{g/L}$ of arsenic, ≤ 4.0 mg/L of phosphate, ≤ 10 mg/L of dissolved iron, and $\text{pH} \leq 7.5$ and produce 8,100 L of arsenic-safe water.

Table 3.1: Groundwater quality treatable by Sono ART as specified by the Proponent and ETV AM

Source Water Quality	[As]/ $\mu\text{g/L}$	pH	Fe(II)/mg/L	PO_4^{3-} /mg/L
Proponent	≤ 750			
ETV-AM	≤ 750	≤ 7.5	≤ 10	≤ 4.0

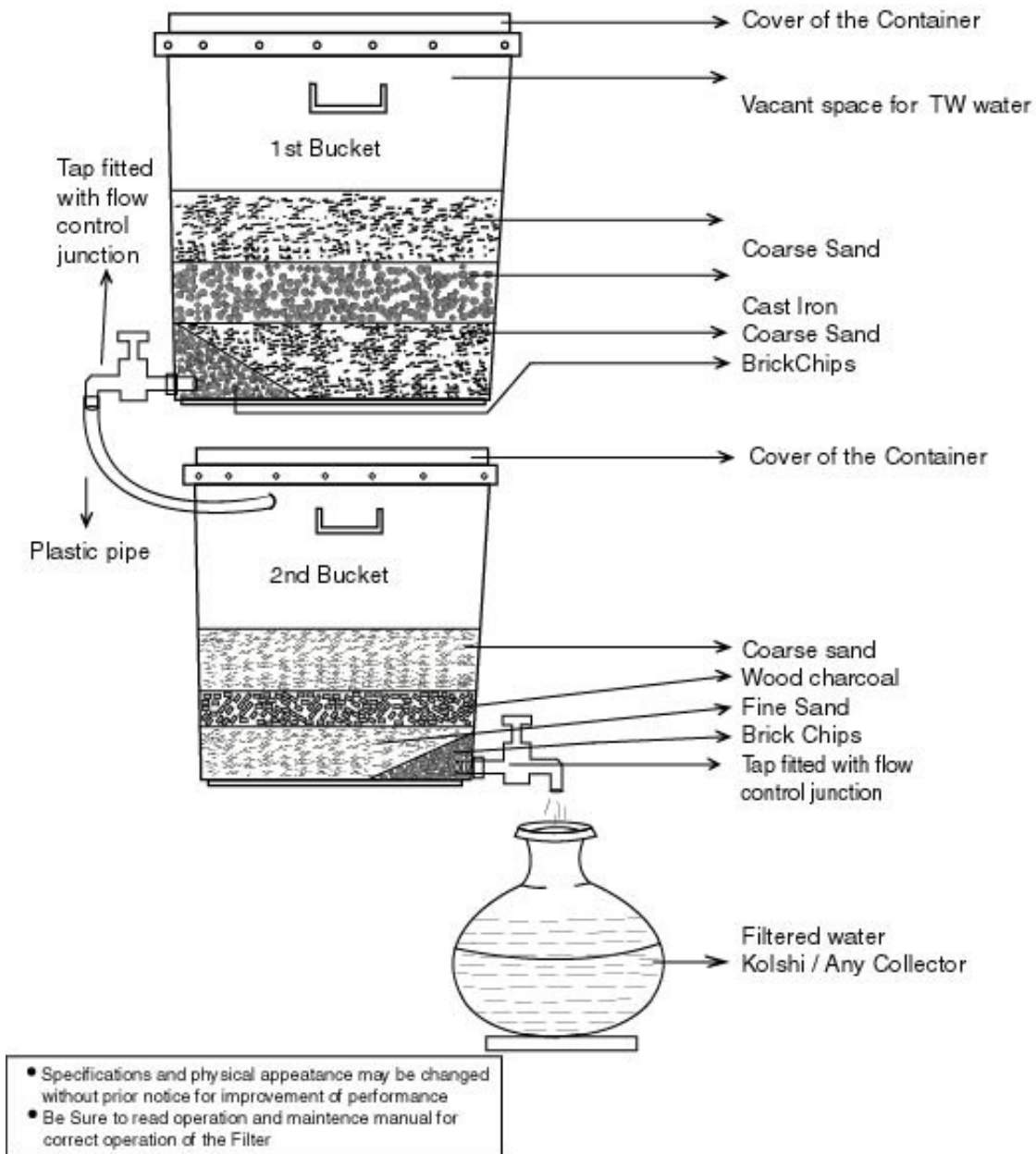


Figure 2: Schematic diagram of the Sono ART

3.3 SITE AND WELL SELECTION

The BETV-SAM project in consultation with BCSIR and the TEC selected Manikgonj, Balagonj, Jhikorgacha, Bera and Chapainawabgonj sites for Sono performance monitoring on the basis of their groundwater quality parameters. Twenty five wells were selected - six wells in each of Bera and Chapai, two wells in Manikgonj, seven wells in Jhikorgacha, and four wells in Balagonj - after preliminary screening of wells in each region. Screening involved analyzing well waters for arsenic, iron, and phosphate using field test kits and selecting suitable wells followed by detailed analysis of the latter wells in an internationally accredited analytical laboratory. These wells were selected on the basis of deployment conditions contained in the provisional verification certificates (**Table 3.1**), and other criteria discussed in section 1.0 above.

The concentrations of arsenic, iron, manganese, and phosphate in wells selected to monitor Sono's performance varied between 103 µg/L and 1205 µg/L, 0.64 mg/L and 13.0 mg/L, 31 µg/L and 1533 µg/L, and 0.6 mg/L and 8.8 mg/L, respectively, and well water pH was around 7.0 ± 1.0 . Eight wells - one in Manikganj, four in Balagonj, and three in Chapai - do not meet deployment conditions set in the provisional verification certificate for arsenic, iron or phosphate. These wells were chosen deliberately in the hope of obtaining and/or identifying the true capabilities of Sono ART and finding deployment conditions that are realistic, appropriate, and based on field observations. A summary of the well water quality parameters are presented in **Table 3.2**.

3.4 TECHNOLOGY INSTALLATION, OPERATION AND MAINTENANCE

All Sono units have been installed by the MA staff as per instructions from the proponent and operated and maintained by end-users under the supervision of the MA field crews. Both the MA field crews and the caretakers have been trained by the proponent in technology installation, operation and maintenance (O&M). The end-users also recorded the daily production volume of arsenic-safe water and engaged in other housekeeping activities. In addition, the MA field crews also convened meetings in the local community from time-to-time, to ensure that the technology is operated and maintained

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properly and the villagers used treated water for drinking and cooking purposes.

The BETV-SAM and BCSIR engineers and scientists trained the MA field crews in taking, preserving, labeling and delivering water samples to the designated analytical laboratories, analyzing samples in the field, and data recording and record keeping procedures. They prepared and delivered weekly and monthly sampling schedules; took regular field trips to make sure that TPM activities proceeded as was designed; and provided on the job training to the MA field crews, answered their questions and responded to their enquiries, and were on hand to deal with any and all issues pertaining to the TPM program.

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Table 3.2: Summary of the well water quality parameters: Mean values \pm CI (confidence interval at 95% confidence level) where the Sono ART were deployed

Location	Well/ Unit ID	[As(T)] $\mu\text{g/L}$	As(III))/ As(T)	[Fe] mg/L	[PO ₄ ³⁻] mg/L	[Mn] $\mu\text{g/L}$	pH
Manikgonj	W14/U1	423 \pm 44	0.81	7.38 \pm 0.28	6.5 \pm 1.0	1445	7.2 \pm 0.4
	W131/U2	118 \pm 12	0.82	3.89 \pm 0.71	3.8 \pm 0.8	1533	6.9 \pm 0.2
	W131/U26	118 \pm 12	0.82	3.89 \pm 0.71	3.8 \pm 0.8	1533	6.9 \pm 0.2
	W131/U27	118 \pm 12	0.82	3.89 \pm 0.71	3.8 \pm 0.8	1533	6.9 \pm 0.2
Balagonj	W09/U3	205 \pm 17	0.95	13.0 \pm 1.65	7.5 \pm 2.4	145	7.0 \pm 0.6
	W11/U4	232 \pm 27	0.99	8.58 \pm 1.04	7.0 \pm 2.5	105	7.0 \pm 0.6
	W39/U5	117 \pm 16	0.93	2.85 \pm 0.28	8.8 \pm 0.5	35	7.3 \pm 0.6
	W34/U6	291 \pm 15	0.95	12.1 \pm 1.38	8.7 \pm 2.3	177	7.0 \pm 0.6
Jhikorgacha	W16/U7	118 \pm 11	0.75	6.6 \pm 0.79	1.8 \pm 0.6	33	7.3 \pm 0.4
	W19/U8	122 \pm 20	0.94	4.15 \pm 0.77	1.54 \pm 0.0	56	7.3 \pm 0.6
	W22/U9	107 \pm 17	0.97	6.76 \pm 1.44	1.5 \pm 0.3	31	7.0 \pm 0.2
	W35/U10	126 \pm 16	0.84	4.85 \pm 0.66	1.6 \pm 0.1	40	7.1 \pm 0.3
	W57/U11	122 \pm 18	0.85	4.63 \pm 0.70	1.4 \pm 0.1	50	7.3 \pm 0.5
	W100/U13	103 \pm 8	0.85	6.46 \pm 0.78	2.2 \pm 0.2	60	7.0 \pm 0.3
	W77/U32	115 \pm 38	0.95	5.55 \pm 0.67	1.9 \pm 0.8	37	6.8 \pm 0.5
Bera	W04/U14	354 \pm 36	0.81	0.64 \pm 0.14	0.6 \pm 0.4	770	7.2 \pm 0.5
	W13/U15	162 \pm 29	0.92	3.60 \pm 0.42	1.0 \pm 0.3	1068	7.3 \pm 1.0
	W26/U16	182 \pm 37	0.77	5.31 \pm 0.40	1.4 \pm 0.5	1167	7.1 \pm 0.1
	W27/U17	560 \pm 58	0.76	3.10 \pm 0.41	0.6 \pm 0.3	1067	7.2 \pm 0.2
	W60/U18	282 \pm 68	0.79	3.14 \pm 0.46	1.7 \pm 0.7	1367	7.2 \pm 0.5
	W28/U19	177 \pm 25	0.71	0.64 \pm 0.16	1.4 \pm 0.3	640	7.3 \pm 0.1
	W28/U28	177 \pm 25	0.71	0.64 \pm 0.16	1.4 \pm 0.3	640	7.3 \pm 0.1
	W28/U29	177 \pm 25	0.71	0.64 \pm 0.16	1.4 \pm 0.3	640	7.3 \pm 0.1
Chapai	W16/U20	1205 \pm 245	0.96	12.4 \pm 0.60	2.9 \pm 0.8	930	7.5 \pm 0.5
	W31/U21	622 \pm 137	1.01	11.4 \pm 0.72	3.1 \pm 1.0	1100	7.4 \pm 0.6
	W32/U22	788 \pm 160	1.12	5.12 \pm 1.05	1.1 \pm 0.2	1050	7.5 \pm 0.6
	W41/U23	557 \pm 71	0.95	8.05 \pm 0.28	2.5 \pm 1.1	1250	7.5 \pm 0.6
	W43/U24	535 \pm 79	0.98	9.55 \pm 0.91	3.4 \pm 0.5	1200	7.6 \pm 0.5
	W14/U25	443 \pm 142	1.07	2.06 \pm 0.38	0.9 \pm 0.5	1200	7.4 \pm 0.2
	W14/U30	443 \pm 142	1.07	2.06 \pm 0.38	0.9 \pm 0.5	1200	7.4 \pm 0.2
	W14/U31	443 \pm 142	1.07	2.06 \pm 0.38	0.9 \pm 0.5	1200	7.4 \pm 0.2

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The Sono unit is designed for a single family and was allowed to produce, on average, about 50 L/day and no more than 57 L/day. The technology operates like a conventional filter with water flowing downward and arsenic dissolved in water is adsorbed onto the media. The technology O&M specified that:

1. Pour approximately 22 – 25 L of well water into the red bucket, and collect potable water from the green bucket in a suitable and clean container.
2. Discard the first three to four batches of treated water.
3. Rinse each bucket with boiling water or hot water (temperature > 70 °C) on a weekly basis to help keep the filter free from pathogens. Add approximately 6 L and 3 L of boiling (or hot) water to the red and green buckets, respectively, allow them to stand for about 30 minutes and then open the tap and empty the buckets.
4. Wash the upper sand layers (either partially or completely) in both buckets to remove iron flocs and replace them every 4 – 6 months in order to prevent clogging of the sand layer and to restore normal flow rate.
5. Poke the valves gently with sewing needle on a regular basis to minimize the effect of clogging with sand and iron flocs.

Some of the above instructions are general and are not useful for “real world” situations, for which specific instructions are needed; and no restrictions were placed on the amount of water to be processed in a day. In addition, the iron composite material could harden, become impermeable if not kept under water at all times, and render the technology ineffective. In order to improve Sono’s performance, the proponent and BETV-SAM made the following instructions that were added to those listed above.

6. The technology should not be used to generate more than 57 L of arsenic-safe water in a day.
7. The media in the red bucket should always be covered with water to prevent iron composite from hardening.

8. The top portion of the sand layers in both buckets are replaced with fresh sand and not washed when the flow rate decreases.

In practice, it was found easier to fill the red bucket with well water and withdraw treated water when needed. Under these operating conditions, Sono ART performed very well and the volume of arsenic-safe water generated by each unit exceeded the amount specified by the ETV-AM program by a factor of at least two and a half.

3.5 SAMPLING AND SAMPLE ANALYSIS

The Monitoring Agency (MA) conducted all field work in consultation with BCSIR and BETV-SAM engineers and scientists. They collected water samples (raw and treated), preserved and delivered them to the designated analytical laboratories or analysed them on-site for arsenic, iron, and other water quality parameters; measured flow rates, recorded daily production rate from caretakers' water consumption sheets, etc. Details on sampling, preservation, labeling, quality assurance and quality control (QA/QC), data recording and record keeping, and other related activities, are given in the Field Monitoring Instructions and Handouts and will not be repeated here. *However, it was necessary to reschedule sampling frequency of treated water because of the technology was not operated as planned. Under the new schedule, the program collected samples at least once a month when the effluent As concentration was $\leq 20\mu\text{g/L}$, two samples a month when the effluent As was between 20 and $29\mu\text{g/L}$, and once a week when effluent As concentration reached to $\geq 30\mu\text{g/L}$. In addition to As, water samples were also analyzed for Fe and PO_4^{3-} and Mn.*

4. EVALUATION OF TECHNOLOGY PERFORMANCE

All Sono units performed well and did not reach breakthrough during the field monitoring period, apart from one unit that reached breakthrough point prematurely. This section presents a summary of the field observation data and assesses Sono's performance for the removal of arsenic, manganese, and other regulated chemicals that are found in groundwater as well as its propensity to harbour and grow bacteriological contamination.

4.1 ARSENIC REMOVAL ABILITY

Sono's ability to remove arsenic from arsenic contaminated groundwater and produce arsenic-safe water was evaluated by collecting and analyzing raw and treated water samples, from each unit, for arsenic and other water quality parameters. A summary of the raw water quality data is presented in the previous section. The following sections will discuss treated water quality parameters.

As discussed before, a number of effluent water samples were collected from each unit and analyzed for arsenic and other water quality parameters. The effluent arsenic concentrations prior to breakthrough from each unit was analyzed statistically (*t*-statistic)⁴ using MINITAB[®]14 software. The results are presented in Table 4.1 along with the volume of arsenic-safe water produced by each unit and shown graphically in Figure 4.1. Also presented in this Table are the *p*-values, which indicates the probability of effluent arsenic concentrations exceeding 50µg/L during the useful life of the arsenic removal media. Figure 4.2 shows a normal probability plot showing expected standard deviations between measured and mean effluent As concentrations vs. effluent As concentration

The salient features of the data presented in Table 4.1 are as follows:

⁴ The *t*-statistic, discovered by W. G. Gosset in 1908, is employed when the number of samples to be analysed 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).

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1. All Sono units performed well and generated $\geq 20,000$ L of arsenic-safe water, apart from two units. These units generated less treated water because the demand for arsenic-safe water was low in one case (U5) and the other unit (U32) started late because the original unit was damaged.
2. Effluent arsenic concentrations prior to breakthrough appears, as demonstrated in **Figure 4.1**, to be independent of the cumulative volume of treated water and fluctuates around a mean value of less than $50 \mu\text{g/L}$. This is supported by the near linearity of the probability plots presented in **Figure 4.2**.
3. The technology performance does not appear to have been affected by the concentrations of arsenic, iron, and phosphate dissolved in groundwater; however, none of the technology reached (apart from one unit) breakthrough point and thus it is too early to draw a definite conclusion.

The data presented in **Table 4.1** shows that the volume of arsenic-safe water generated by different Sono units is about less than or one-third of the proponent's performance claim. This is because these units have not been used long enough to generate that much potable water. However, **Figure 4.1** clearly demonstrates that none of the units, apart from one, are about to reach breakthrough point. Moreover, the mean effluent arsenic concentration from 26 units is less than $10 \mu\text{g/L}$; perhaps indicating that the breakthrough point may not be reached any time soon. Although the observed data does not allow a prediction as to whether the technology will be able to meet the proponent's original performance claim and produce 74,000 L of arsenic-safe water or not, they do demonstrate that the Sono ART has the ability to generate a much high volume of arsenic-safe water than specified by the ETV-AM program.

Twenty six units out of thirty one – or about 84% of the deployed units - produce $\geq 21,000$ L of arsenic-safe water and as noted before, only one of the units reached breakthrough point. This is despite the fact that the water quality parameter of some of the wells (8 out of 25) exceeded the deployment conditions specified by the ETV-AM program. It is, therefore, concluded that the technology can play an important role in providing arsenic-safe water to people in arsenic affected areas of Bangladesh provided

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that it is installed on appropriate wells and operated and maintained following instructions provided in this document.

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Table 4.1: Total effluent arsenic concentrations, associated significance level (p-values), and the cumulative volumes of treated water generated by different Sono units

Location / Unit	No. of Data Points	[As(T)] _{EFF} / µg/L Mean ± CI ⁵	P-value ⁶	Cumulative Volume/L
Ma/U1	14	5±1	0.000	>22264
Ma/U2	15	4±1	0.000	>21020
Ma/U26	16	4±1	0.000	>22219
Ma/U27	16	5±2	0.000	>23118
Ba/U3	16	3±1	0.000	>23000
Ba/U4	16	5±1	0.000	>21672
Ba/U5	38	27±3	0.000	>16168
Ba/U6	16	10±3	0.000	>24400
Jh/U7	16	2±1	0.000	>24007
Jh/U8	16	3±1	0.000	>21754
Jh/U9	16	3±1	0.000	>22902
Jh/U10	14	6±3	0.000	>23940
Jh/U11	15	2±1	0.000	>22735
Jh/U13	15	3±1	0.000	>19353
Jh/U32	14	8±2	0.000	>16935
Be/U14	40	38±5	0.000	>23100
Be/U15	15	3±2	0.000	>23190
Be/U16	14	4±5	0.000	>22270
Be/U17	20	12±4	0.000	>20910
Be/U18	14	9±5	0.000	>25440
Be/U19	21	16±4	0.000	>21660
Be/U28	30	16±5	0.000	>22120
Be/U29	15	2±2	0.000	>24760
Ch/U20	14	2±1	0.000	>21790
Ch/U21	14	1±1	0.000	>22930
Ch/U22	14	4±1	0.000	>24450
Ch/U23	14	2±1	0.000	>23750
Ch/U24	15	4±2	0.000	>26540
Ch/U25	15	2±1	0.000	>21450

⁵ CI stands for confidence interval

⁶ P-values less than 0.05 (i.e. at 95% confidence level) indicate the probability of effluent arsenic concentration exceeding 50µg/L

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Ch/U30	14	3±1	0.000	>20370
Ch/U31	14	4±3	0.000	>26340

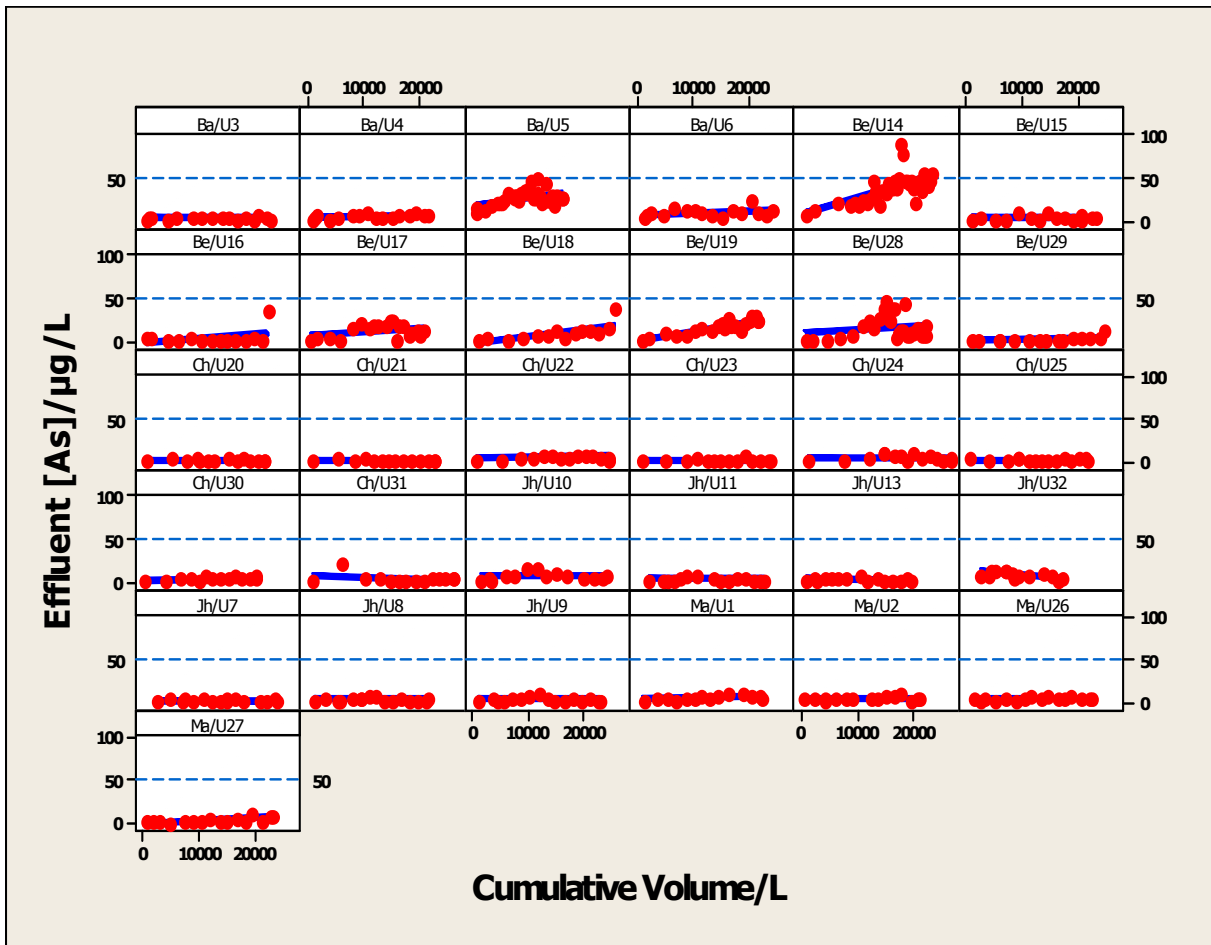


Figure 4.1: Plots showing effluent arsenic concentrations from different Sono units as a function of volume of treated water

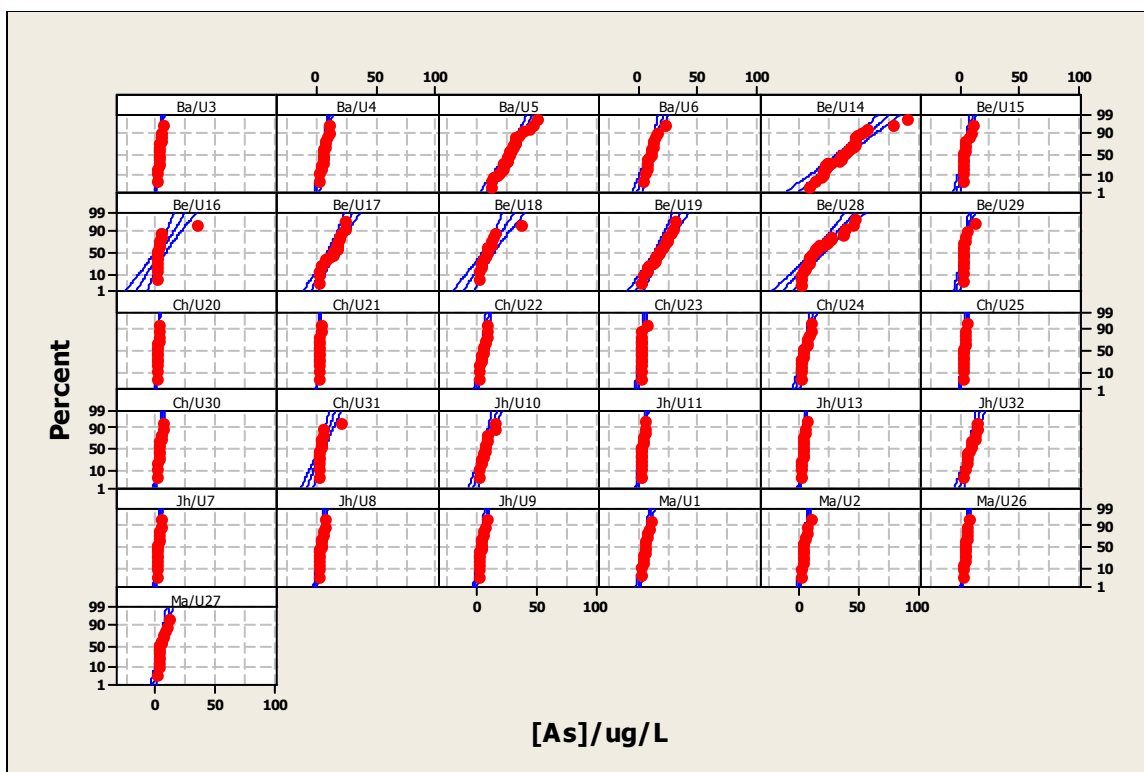


Figure 4.2: Normal probability plots showing expected standard deviations between measured and mean effluent As concentrations vs. Effluent As concentration

4.2 REMOVAL OF OTHER CHEMICALS

In addition to arsenic, raw and treated water samples were also analyzed for a host of other natural as well as technology-specific chemicals and bacteriological contamination. These findings have implications for the technology performance, the quality of water it generates and the handling and disposal of the wastes it generates.

For example, groundwater in Bangladesh is also known to contain manganese (Mn) at levels that exceeds the WHO guideline of 0.4 mg/L. Thus, raw and treated water were analyzed for Mn and the results are presented in **Table 4.2**. As can be seen, Mn concentrations in fourteen (14) wells - out of twenty five (25) wells selected to monitor Sono performance - were contaminated with ≥ 0.4 mg/L of Mn. The data also show that Sono ART was able to remove Mn from raw water and reduce its concentration to below 0.4 mg/L in all cases.

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Other chemicals that are found in groundwater in Bangladesh are barium (Ba), chromium, lead, nickel, and fluoride. Of these chemicals, only barium was found to be present at concentrations that exceed Bangladesh drinking water standard of 10µg/L in all wells, but not the WHO guideline of 1 mg/L. The concentrations of Ba in the raw and treated water are presented in **Table 4.3**. As can be seen, Ba concentrations in groundwater varied between 62µg/L and 530µg/L and the fraction of Ba removed by the technology is about 50%.

Table 4.2: Mean influent and effluent concentrations of manganese for different Sono units

Location	Well/unit ID	No. of Data Points	[Mn] _{Inf} µg/L	No. of Data Points	[Mn] _{Eff} µg/L
	W28/U19		640		49
	W28/U28	4	640	9	78
	W14/U1	3	1445	7	179
	W28/U29	3	640	5	28
Manikgonj	W16/U2	3	1533	7	60
	W16/U26	3	930	2	388
	W31/U26	3	1533	4	143
	W31/U21	2	100	4	143
	W13/U27	3	1533	4	52
	W32/U22	3	1030	4	330
Chapai	W09/U3	2	145	3	290
	W41/U23	2	1250	1	270
Balagonj	W11/U4	2	105	3	111
	W43/U24	2	1200	3	200
	W39/U25	3	350	5	7
	W17/U25	2	1200	1	62
	W34/U90	2	1200	3	200
Jhikorgacha	W16/U7	2	33	3	195
	W19/U8	2	56	4	44
	W22/U9	2	31	2	109
	W35/U10	1	40	1	260
	W57/U11	2	50	1	49
	W100/U13	2	60	2	115
	W77/U32	2	37	3	97
Bera	W04/U14	3	770	16	40
	W13/U15	4	1068	7	100
	W26/U16	3	1167	5	336
	W27/U17	3	1067	7	113
	W60/U18	3	1367	4	339

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Table 4.3: Mean influent and effluent concentrations of barium for different Sono units

Location	Well/unit ID	No. of Data Points	[Ba] _{Inf} /µg/L	No. of Data Points	[Ba] _{Eff} µg/L
Manikgonj	W14/U1	3	132	2	47
	W131/U2	2	130	3	30
	W131/U26	2	130	2	46
	W131/U27	2	130	2	31
Balagonj	W09/U3	1	70	3	24
	W11/U4	1	62	3	32
	W39/U5	2	86	3	16
	W34/U6	2	115	3	41
Jhikorgacha	W16/U7	1	530	2	238
	W19/U8	1	230	2	122
	W22/U9	1	430	2	205
	W35/U10	1	160	2	175
	W57/U11	1	260	2	98
	W77/U12	1	360	3	260
	W100/U13	1	330	2	60
Bera	W04/U14	2	91	3	49
	W13/U15	3	152	3	51
	W26/U16	2	180	3	77
	W27/U17	2	185	3	97
	W60/U18	2	140	2	66
	W28/U19	2	110	3	57
	W28/U28	2	110	3	56
	W28/U29	2	110	3	38
Chapai	W16/U20	2	216	2	90
	W31/U21	1	260	2	86
	W32/U22	1	210	1	130
	W41/U23	1	230	1	120
	W43/U24	1	260	1	150
	W14/U25 (T)	2	150	1	69
	W14/U30 (T)	2	150	1	88

4.3 PROPENSITY FOR BACTERIAL CONTAMINATION

The MA field crews, sample handlers and analyzers, and caretakers were given adequate personal hygiene instructions and were reminded on the importance of hygiene in order to prevent bacterial contamination in raw, treated water and the technology. This, however, does not totally eliminate the possibility of contamination of water or the equipment. It was for this reason that raw and treated water in Manikganj, Balagonj and Bera were analyzed for thermo-tolerant coliform (TTC) and *E-coli*. These sites were selected because samples taken in these sites could be delivered to the designated laboratory within 6 hrs of sampling. The bacteriological test results presented in **Table 4.4a, 4.4b and 4.4c** show that:

1. The well waters are generally free from microbial contamination and any contamination found in raw water is most likely introduced at one point or another through the chain of events from sampling to samples analysis.
2. The treated water samples from some units were occasionally found to be contaminated with low to moderate level of bacterial contaminations.
3. The frequency of contamination varied from unit to unit and it is believed to have been introduced by caretakers, samplers, sample handlers, analysts, and others.
4. Sono ART does not harbor, foster, or grow bacteria.

Table 4.4a: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Sono units in Balagonj

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W09/U3	16-Jan-08	1	0	0	
W09/U3	30-Jan-08	1	0	2	0
W11/U4	16-Jan-08	8	1	5	0
W11/U4	30-Jan-08	3	0	11	2
W39/U5	16-Jan-08	42	23	5	0
W39/U5	30-Jan-08	6	3	1	0

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Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W39/U5	13-Mar-08	5	1	8	0
W34/U6	16-Jan-08	0		1	1
W34/U6	30-Jan-08	0		0	

Table 4.4b: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Sono units in Manikgonj

Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W14/U1	7-Feb-08	0		0	
W14/U1	1-Apr-08	0		0	
W14/U1	29-Apr-08	0		0	
W14/U1	23-Jun-08	0		0	
W14/U1	23-Jun-08	0		0	
W14/U1	27-Aug-08	0		0	
W14/U1	16-Sep-08	0		3	3
W14/U1	17-Dec-08	1	0	0	
W131/U2(T)	1-Apr-08	0		0	
W131/U2(T)	24-Jun-08	0		0	
W131/U2(T)	24-Jun-08	0		0	
W131/U2(T)	17-Sep-08	1	0	0	
W131/U2(T)	21-Dec-08	0		0	
W131/U26(T)	27-Feb-08			0	
W131/U26(T)	29-Apr-08			124	1
W131/U26(T)	24-Jun-08			0	
W131/U26(T)	27-Aug-08			0	
W131/U26(T)	27-Aug-08			0	
W131/U26(T)	17-Sep-08			2	0
W131/U26(T)	21-Dec-08			0	

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Well/Unit ID	Sampling Date	Influent		Effluent	
		TTC	E. Coli	TTC	E. Coli
W131/U27(T)	27-Feb-08			5	1
W131/U27(T)	1-Apr-08			0	
W131/U27(T)	29-Apr-08			0	
W131/U27(T)	24-Jun-08			0	
W131/U27(T)	27-Aug-08			2	0
W131/U27(T)	27-Aug-08			0	
W131/U27(T)	17-Sep-08			0	
W131/U27(T)	21-Dec-08			0	

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Table 4.4c: The concentrations (counts/100 mL) of TTC and *E. coli* in raw and treated water samples taken from Sono units in Bera

Site/Unit ID	Sampling Date	Influent		Effluent	
		TTC	<i>E. Coli</i>	TTC	<i>E. Coli</i>
W04/U14	6-Mar-08	0		0	
W04/U14	8-Apr-08	0		1	0
W04/U14	11-May-08	0		11	8
W04/U14	8-Jun-08	22	6	0	0
W04/U14	8-Jun-08	5	0	2	0
W04/U14	10-Jul-08	0		0	
W04/U14	24-Jul-08	0		0	
W04/U14	19-Aug-08	3	2	0	
W04/U14	11-Sep-08	6	0	2	0
W13/U15	6-Mar-08	0		29	0
W13/U15	8-Apr-08	0		0	
W13/U15	11-May-08	1	0	3	2
W13/U15	13-Jul-08	0		0	
W13/U15	13-Jul-08	0		0	
W13/U15	14-Sep-08	0		0	
W13/U15	21-Oct-08	0		0	
W13/U15	15-Dec-08	0		57	30
W13/U15	19-Jan-08	13	1	0	
W26/U16	6-Mar-08	0		0	
W26/U16	8-Apr-08	0			
W26/U16	11-May-08	89	6	0	
W26/U16	13-Jul-08	0		0	
W26/U16	13-Jul-08	0		0	
W26/U16	14-Sep-08	0		1	0
W26/U16	13-Oct-08	0		0	
W26/U16	17-Dec-08	0		0	
W26/U16	19-Jan-08	0		0	

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Site/Unit ID	Sampling Date	Influent		Effluent	
		TTC	<i>E. Coli</i>	TTC	<i>E. Coli</i>
W26/U16	6-Mar-08	9	1	0	
W27/U17	8-Apr-08	26	0	0	
W27/U17	7-May-08			0	
W27/U17	11-May-08	9	1	0	
W27/U17	13-Jul-08	28	0	3	0
W27/U17	13-Jul-08	32	0	2	0
W27/U17	25-Aug-08	16	0	0	
W27/U17	14-Sep-08	34	0	0	
W27/U17	9-Nov-08	1	0	0	
W27/U17	17-Dec-08	2	0	0	
W27/U17	8-Feb-09	6	0	0	
W27/U17	22-Feb-09	3	0	0	

5 RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR SONO

5.1 RECOMMENDATION

Thirty one units of Sono ART have been deployed and installed on 25 wells - triplicate units were installed on three wells - in five different regions of Bangladesh and operated by the end users under the supervision of the MA field crews under “real world” conditions. 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 their media life except unit #14 due to the hardening of iron composite materials. The hardening of arsenic removal media and the premature failure of this unit indicate that it was not operated properly, i.e. media in the red bucket was not covered with water at all times.
2. The technology - with the exception of two (2) units - generated between 20,000L and 26,000 L of arsenic-safe water. The reasons for lower production of potable water by the two units have been discussed before.
3. The data presented in the previous section show that there are no indications of imminent arsenic breakthrough (see **Figure 4.1**) except in the case of U14.
4. The performance of Sono ART exceeded that reported by the ETV-AM by at least 2.5 fold.

The technology can provide arsenic-safe water to people in arsenic affected areas of Bangladesh by following the deployment conditions specified below. BETV-SAM, on the basis of performance monitoring and evaluation presented in this report, recommends that Sono ART be certified for marketing and sale in Bangladesh.

5.2 CONDITIONS FOR DEPLOYMENT OF SONO ART

The performance monitoring data presented and analyzed in previous sections indicate that Sono ART can produce arsenic-safe water if it is deployed on wells that meet the

deployment conditions specified below. The performance monitoring data also show that the treated water is prone to biological contamination. The adverse health effect of bacterial contaminated treated water could overwhelm the gains made from removing arsenic. It is for these reasons that BCSIR recommends that the technology should be deployed under the following terms and conditions.

5.2.1 Deployment Condition

1. The technology can produce arsenic-safe water that meets Bangladesh drinking water standard from well water contaminated with $\leq 1200 \mu\text{g/L}$ of As, $\leq 9.0 \text{ mg/L}$ of phosphate, $\leq 1.5 \text{ mg/L}$ of manganese, $0.0 - 13 \text{ mg/L}$ of iron, and $\text{pH } 7.0 \pm 1.0$.
2. A Sono unit, installed and operated following the above instructions, should be able to provide arsenic-safe water to a single family, 45 L to 50 L per day or more, for at least two years and generate $\geq 32,000 \text{ L}$ of arsenic-safe water.
3. The well water should be analyzed before the deployment and installation of a Sono unit to make sure that well water meets conditions specified in **Condition #1** above.
4. The proponent must supply an *Installation, Operation and Maintenance Manual* that contains the **RECOMMENDATION AND DEPLOYMENT CONDITIONS FOR SONO**.
5. The technology should not be used to produce $\geq 57 \text{ L}$ of arsenic-safe water in a day.
6. The red and green buckets should be washed at least once a week with 6L and 3 L of boiling water, respectively, to prevent bacteriological contamination and growth. The unit should be washed similarly if not used for two consecutive days.
7. The red bucket should always be filled with well water, withdrawn when arsenic-safe water is needed and replaced with fresh well water.
8. When covered with iron flocs, the top portion of the sand layers in the red and green buckets should be removed carefully and replaced with fresh layers of clean sand. The proponent will provide accurate procedures for collection, washing, and sterilization of sands to replace those removed from each bucket.

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9. 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.
10. The technology proponent must comply with the Government of Bangladesh approved National Waste Management Protocol for safe disposal of arsenic wastes generated by Sono ARTs.

5.2.2 Hygiene Practice

1. The end-users should wash their hands with soap and plenty of water and make sure that they are absolutely clean before adding water to the Sono unit or collecting from it, removing sand covered with iron flocs (**Section 5.2.1; point #7**), or servicing the Sono unit in any other way.
2. The pots or pans used to collect well water and/or treated water and to collect, wash, and sterilize sands to replace those removed from Sono (**Section 5.2.1; point #7**) should be cleaned thoroughly. To do this, add about 2 L of water to the pot, add one tea-spoon of either Chlotech solution or bleach powder to the water, mix it well, swirl it around a number of times and then throw it away then, rinse with clean water.

5.2.3 Technology Monitoring and Replacement

1. The treated water should be tested for arsenic six month after installation, and once every two month thereafter as a precautionary measure and to ensure that treated water does not contain unacceptable levels of arsenic.
2. Replace the unit when arsenic concentration in the treated water is greater than 40 $\mu\text{g/L}$.
3. A Sono unit that is deployed following the above conditions to serve a single family should be able to produce arsenic-safe water for at least two years at a rate of 45L/day. Therefore, the unit have to be replaced with a new one after two years, if treated water cannot be analyzed in a testing facility 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 Sono unit's filtration media (and thus the unit as a whole) has possibly reached the end of its useful life.

The technology proponent must supply an Installation, Operation and Maintenance manual to the users that incorporates the above directives and must train at least one persons to be responsible for technology operation and maintenance.

5.2.4 Technology Users Support Systems

This section deals with the support system for the technology user. Sono 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 Sono ART.

1. ***Analysis of treated Water for Arsenic:*** As suggested above, Sono technology users should replace the Sono unit after two years, unless they can have water treated by their Sono unit and know that after two years, 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 two 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 Sono 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

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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 oversee 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 Sono break down often enough and have to be replaced. For most households, reaching the Sono 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 Sono 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, Sono ought and should stock-up spare parts and supply them to distribution offices, vendors, etc.

ANNEX A: COST ANALYSIS

The following Table provides the cost of production of arsenic-water (per Litre and per day) to Sono ART users. The calculation does not take into account the cost of replacement of broken taps and other repair costs. This is because the technology vendor guarantees Sono for five years and the guarantee should cover any repair costs.

Table A1: Household arsenic-safe water production costs

Considerations and Description	Quantity	Basic Cost
Sono ART Unit Cost	1	Tk2,700 ⁷
Daily Production Volume	45	
Technology Longevity / Media lifespan ⁸	2	
Volume of Arsenic-Safe Water Produced in Two (2) Years	33,000	
The Cost of Treating One Liter of Water		Tk0.12
Daily Water Consumption Const		Tk5.52
Monthly Water Consumption Cost⁹		Tk166

NOTES:

The cost estimates presented in the above Table is based on the assumption that:

1. A household consumes 45 L of arsenic-safe water in a day.
2. It understood that a Sono ART has to be replaced in its entirety with a new unit.

Thus, no depreciation costs are included in the cost estimates.

⁷ Price quoted by the vendor on the phone and could change

⁸ Based on TPM data

⁹ 30 days per month

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3. The technology has to be replaced with a new one if there are no facilities to test Sono treated water for arsenic. Consequently, sample analysis costs are not included in the cost estimates.