

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

**FIELD TESTING AND PERFORMANCE
EVALUATION**

OF

**SHAWDESH HOUSEHOLD ARSENIC
REMOVAL TECHNOLOGY**

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1. Introduction

The Shawdesh Aqua Filter (SAF), a household arsenic removal technology (ART), 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 SAF 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 fifteen (15) to twenty (20) days. 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 SAF ART. The analysis of field data, primarily arsenic, iron and phosphate concentrations and solution pH in raw and treated water was carried out employing MINITAB¹ 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

The SAF ART employs coagulation and flocculation processes to remove arsenic from arsenic contaminated water. The technology is consists of two plastic buckets that are housed on a tripod one above the other and the reagents packets. The buckets, which can hold 30 L of water individually, are fitted with a water tap, about two inches off the bottom of the bucket. The taps are covered, from inside the bucket, with a cloth filter to filter out iron sludge, sands, and other particles. A flexible tubing is used to direct effluent from the upper bucket into the lower one. The upper bucket is used for coagulation and flocculation and the lower bucket, which is filled from the bottom with 50 g of charcoal (place around the water tap) and 15 kg of sand (20% 40µm mesh size,

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

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56% 70 μm mesh size and 24% 140 μm mesh size), is used as a filtration device to filter out the suspended solids, including the arsenic containing iron oxyhydroxide particulates. The schematic drawing of the unit is shown in Figure 1 and a photograph of an assembled unit is shown in Figures 2.

The following steps are taken to treat arsenic contaminated well water.

1. Twenty five (25) liter of well water is added to the top bucket.
2. The bucket is spiked with 4.5 mL to 5.5 mL of 5.5% chlorine solution, stirred well with a rod or a clean wooden stick and allowed to stand for 10 minutes.
3. The content of a reagent packet is added next and the solution stirred well with a rod or a clean wooden stick and allowed to stand for an hour.
4. After one hour, the treated water is allowed gently into the second bucket to filter out the suspended solids, including the arsenic containing iron oxyhydroxide particulates, and destroy remaining chlorine.
5. The effluent is collected in a clean bucket.

The field testing was conducted over a period of fifteen (15) to twenty (20) days following the Technology Specific Test Plan (TSTP). Over the length of the field test program, samples of raw and treated water were collected and analysed for different water quality parameters as described in TSTP.

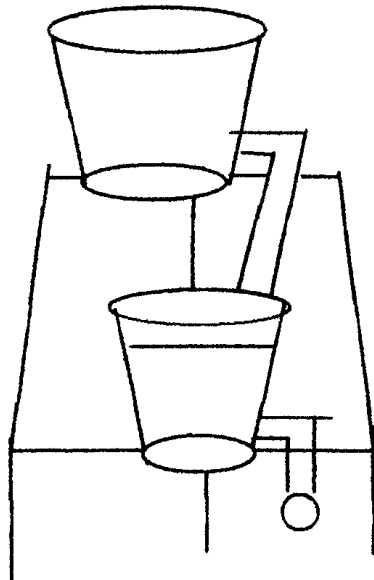


Figure 1: Schematic diagram of a Shawdesh Aqua Filter



Figure 2: Photograph of Shawdes Aqua Filter (picture is now the correct one)

3. Proponent's Technology Performance Claim

The proponent claims that the SAF ART can produce arsenic-safe water from well water that is contaminated with up to 750 $\mu\text{g/L}$ arsenic, 10 mg/L of phosphate and under pH conditions that are typical of most groundwater in Bangladesh. The filter can process 25 L of groundwater in approximately 6 hrs and generate approximately 50 L of arsenic safe potable water in 12 hrs

4. Verified Performance Statement

- 4.1 The SAF ART has been field tested on five wells, one unit on well in Begumgonj, Dodar, Chapai and two units on wells in Chandina and Ishwardi. A summary of the well water quality parameters along with their corresponding 95% CI (confidence intervals) is provided in **Table1**.

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- 4.2 The field tests measured the volume of water that can be treated by the technology over an approximately twelve (12) hours period in a day.
- 4.3 During the field testing, raw and treated water samples were collected and analysed for concentrations of dissolved arsenate and arsenite, iron, phosphate and other water quality parameters. The effluent arsenic data were analysed statistically using INITAB14 statistical software.
- 4.4 The effluent arsenic concentration has been analyzed statistically employing t-statistic² and the results are presented in **Table 2** and shown graphically in **Figure 3**. The results show that:
- A) The data appears to be randomly distributed around a mean value before arsenic breakthrough,
 - B) The mean effluent arsenic concentration before breakthrough is less than 50 µg/L with 95% confidence, and
- 4.5 The SAF technology was able to produce 45-50 L of arsenic-safe water over a period of 12 hrs from well waters that were contaminated with arsenic, iron and phosphate at concentrations of up to 650 µg/L, 7 mg/L and 8 mg/L, respectively, and under pH conditions stated in Table 1.

Table 1: Summary of the well water quality parameter

Location/ Unit	[As]µg/L Mean ±CI ³	As(III)/ As(T)	[Fe]mg/L Mean ±CI	[PO ₄ ⁻³]mg/L Mean ±CI	pH Mean ±CI
Begumgonj/U4	299 ± 12	0.87	6.36 ± 0.50	8.21 ± 0.54	7.5 ± 0.1
Chandia/U5	245 ± 36	0.95	2.88 ± 0.20	6.49 ± 0.80	7.5 ± 0.1
Chapai/U1	772 ± 53	0.72	1.25 ± 0.16	1.64 ± 0.42	7.2 ± 0.0
Dohoar/U3	444 ± 17	0.89	6.9 ± 0.45	5.87 ± 0.37	7.2 ± 0.1
Ishwardi/U2	395 ± 50	0.85	3. 81 ± 0.25	1.09 ± 0.11	6.9 ± 0.0

² The **t-statistic**, discovered by W. G. Gosset in 1908, is employed when 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).

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

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Table-2: Summary of statistical analysis (*t- statistic*) of arsenic concentrations in SAF treated water sample in different location

Location/Unit	No of Data Point	[As] $\mu\text{g/L}$ Mean \pm CI	P ⁴	Verification of Performance
Begumgonj/U4	15	2 \pm 0	0.000	Verified
Chandia/U5	15	3 \pm 3	0.000	Verified
Chapai/U1	16	1 \pm 0	0.000	Verified
Dohoar/U3	13	6 \pm 3	0.000	Verified
Ishwardi/U2	17	1 \pm 0	0.000	Verified
Begumgonj/U4	17	2 \pm 1	0.000	Verified
Chandia/U5	16	2 \pm 1	0.000	Verified

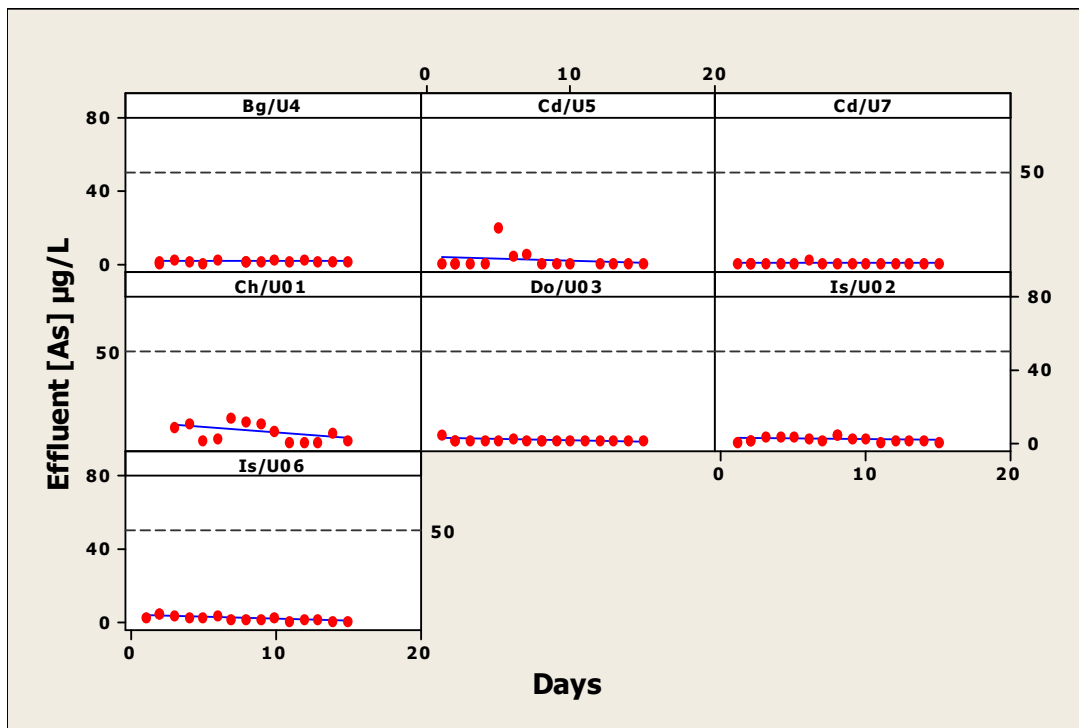


Figure 3: Plots Showing Effluent Arsenic Concentrations in Treated Water vs. Testing Day

⁴ ⁵The probability of obtaining a sample mean if the true sample mean is really equal to 50 $\mu\text{g/L}$ as was hypothesized. If the p-value is less than or equal to the corresponding α -level (0.05 in this case), the null hypothesis (mean = 50 $\mu\text{g/L}$) can be rejected.

5. Evaluation of Additional Technology Performance Characteristics

In addition to analysing 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. These findings have implications for the technology performance, the quality of water it generates and the handling and disposal of the wastes it generates.

5.1 Daily Production Capacity

The volume of water treated in a day by the technology varied from about 45L to 50L. This is in reasonable agreement with the proponent's claim.

5.2 Removal/Addition of Manganese

A number of influent and effluent samples have been analysed for manganese, silicon, boron, barium, sodium, and others by metal scan. The test results presented in **Table 3** show that SAF technology was adding manganese to the treated water. The manganese originates from ferric sulfate employed for coagulation/flocculation process. Analysis of a solution ferric sulfate used by the proponent in the BETV-SAM analytical lab shows that ferric sulfate contains about 0.06% Mn.

Table-3: Status of removal Manganese

Location/Unit	Influent [Mn]/ $\mu\text{g}/\text{L}$ Mean \pm CI	Effluent [Mn]/ $\mu\text{g}/\text{L}$ Mean \pm CI
Bg/U4	550 ⁵	543 \pm 186
Cd/U5	150 ⁶	906 \pm 415
Cd/U7		1043 \pm 342
Ch/U1	1433 \pm 143	1666 \pm 286
Do/U3	616 \pm 28	967 ⁶
Is/U2	1533 \pm 143	1500 \pm 430
Is/U6		1400 \pm 248

⁵ A single sample was analyzed.

5.3 Other Chemicals added by the Technology

The SAF technology employs ferric sulphate, and Sodium hypochlorite. Raw and treated water samples were analysed for chloride (Cl⁻), sulphate (SO₄²⁻), and others by ion chromatography to make sure that their concentrations do not exceed the Bangladesh Drinking Water Standard. The ion chromatography and the metal scan data indicate that:

- A. As expected, the technology adds low level of chloride and sulfate ions to the treated water,
- B. Adds low level of zinc to the treated water, which again may be present in the ferric sulfate, and
- C. The concentrations of sulphate and zinc added to the treated water are much less than those of the Bangladesh Drinking Water Standard.

The influent and effluent concentrations of chloride, sulphate and zinc in different well waters are presented in **Table 4**.

Table 4: Influent and effluent concentrations of Zn and sulphate

Location/Unit	Average [Zn]/ µg/L		Average [SO ₄ ²⁻]/ mg/L		Average [Cl ⁻]/ mg/L	
	Influent	Effluent	Influent	Effluent	Influent	Effluent
Bg/U4	8	101	0.66	163.0	946.3	794.7
Cd/U5	0	64	0.51	179.3	54.5	57.9
Cd/U7		273		177.3		58.2
Ch/U1	4	123	0.87	177.0	15.6	30.5
Do/U3	3	313	0.35	122.5	4.2	31.9
Is/U2	6	167	0.33	148.0	4.5	26.1
Is/U6		167		147.0		26.0
Bangladesh STD	5000 µg/L		400 mg/L		150 - 600 mg/L	

Since the technology employs chlorine, a few treated water samples were also analysed for chlorinated phenols and volatile organic compounds, the by-products of chlorination process. No chlorinated phenols were detected in the treated water; however, low level of carbon tetrachloride and dibromomethane were found in the

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treated water and presented in **Table 5**. The concentration of carbon tetrachloride is much lower than the recommend level of 4 µg/L and there are no guideline values for the other two compounds.

Table 5: Concentration of carbon tetrachloride and dibromomethane in the Shawdesh Treated water

Source Water\VOC	Carbon Tetrachloride/ µg/L	2,2-Dichloropropane/ µg/L	Dibromomethane/ µg/L
Shawdeh treated water	0.26	1.38	0.95

5.4 Bacteriological Contamination

Samples of raw and treated water have been analysed for thermotolerant bacteria (TTC) and *E.coli*. The test results, presented in **Table 6**, show that:

- A. The well waters are free from bacteriological contaminations and the contamination observed in Dohar is believed to originate from improperly cleaned sand used for sand filtration.
- B. Approximately 50% of the treated water samples were found to be contaminated with moderate to high level of TTC; and one sample was found to be contaminated with high level of *E.coli*.
- C. The observed bacterial contaminations are most likely introduced by the technology operators, sample handlers, or the analysts.
- D. The data trend does not indicate that the SAF ART foster the growth of biological contaminations. The growth found can be related to secondary contamination.

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Table-6: Results of Bacteriological test results on raw and treated water from SAF units

Location/Unit	Sampling date	Influent		Effluent	
		TTC/ Counts/100 mL	<i>e.coli</i> Counts/100 mL	TTC Counts/100 mL	<i>e.coli</i> Counts/100 mL
Cd/U5	16-Jul-09	0		350	0
Cd/U5	22-Jul-09	0		360	0
Cd/U5	22-Jul-09	0		280	0
Cd/U5	22-Jul-09			0	
Cd/U5	26-Jul-09	0		0	
Cd/U7	16-Jul-09			360	0
Cd/U7	22-Jul-09			220	0
Cd/U7	22-Jul-09			0	
Cd/U7	26-Jul-09			100	0
Is/U02	26-Jul-09	0		4000	1000
Is/U02	02-Aug-09	0		0	
Is/U02	02-Aug-09	0		600	0
Is/U02	02-Aug-09			23	0
Is/U02	09-Aug-09	0		0	
Is/U06	26-Jul-09			30	0
Is/U06	02-Aug-09			0	
Is/U06	02-Aug-09			0	
Is/U06	02-Aug-09			0	
Is/U06	09-Aug-09			0	
Do/U03	21-Jul-09	4	0	90	0
Do/U03	23-Jul-09	22	0	30	0
Do/U03	23-Jul-09	33	0	82	0
Do/U03	23-Jul-09			0	
Do/U03	27-Jul-09	64	1	100	0

6. Waste Characterization

The sludge generated by the Shawdeh ART along with a sample of charcoal and sand from the same unit in two sites – one with the highest arsenic and one with the low

arsenic in well water – were characterized for toxicity following the Toxicity Characteristic Leaching Procedure (TCLP) and the Total Available Leaching Procedure (TALP). These tests were conducted on a homogeneous sample of the sludge collected 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 7**. As expected, arsenic accumulated in sludge is proportional to the arsenic level in well water and the arsenic contents of the sands and charcoals 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 7: Arsenic content of the Iron sludge, the filter media and leachates

Location	Sample	Arsenic Content [mg/kg]	Arsenic leaching from media	
			TCLP	TALP
Chapai	Iron Sludge	5051	43	40
	Sand	9	7	14
	Charcoal	7	48	24
Ishwardi	Iron Sludge	2420	10	125
	Sand	42	7	3
	Charcoal	6	236	112

7. Recommendation and Deployment Conditions for SAF Technology

The field test data presented and analyzed in previous sections indicate that Shawdesh Aqua Filtr (SAF) ART can produce arsenic-safe water if it is deployed on wells that meet the deployment conditions specified below. 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. In addition, the ferric salt used is impure and there are no way of knowing the level of purity of this chemical from its present source in future. It is for these reasons

that BCSIR makes the following recommendations and deployment conditions for SAF ART.

7.1 Recommendations

Seven units of SAF ART have been 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 produced treated water with less than 10 µg/L of arsenic (see Figure 3).
2. The technology generated between 45 and 50 L of arsenic-safe water in a day.
3. The technology adds zinc and manganese to the treated water

Clearly, the technology can provide arsenic-safe water to people in arsenic affected areas of Bangladesh by following the deployment conditions specified below and acquiring analytical grade ferric sulfate. Therefore, it is recommended that SAF ART be certified for marketing and sale in Bangladesh subject to following conditions.

7.2 Deployment Conditions

The field test data presented in previous section show that SAF ART can produced arsenic-safe water if it is deployed on wells that meet the conditions specified below. Moreover, the treated water can be protected from biological contaminations if operators practice appropriate hygiene.

7.2.1 Deployment Conditions

SAF ART can produce arsenic-safe safe water if it is installed on wells that meet 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 7.4 ± 2.1 mg/L of iron,] 8.4 ± 2.6 mg/L of phosphate, 647 ± 252 µg/L arsenic and pH 7.5 ± 0.1 .
2. The technology cannot remove manganese from well water and 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 SAF unit to make sure that well water meets conditions specified in sections 7.2.1 and 7.2.2 above.
4. The water quality of at least 5% of the wells selected for the technology deployment under the conditions stated in 7.1 above should be analysed at BCSIR analytical research division or other analytical laboratories in order to be able to verify deployment conditions for SAF ART.
5. 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.
6. The proponent must supply an *Installation, Operation and Maintenance Manual* that contains the deployment conditions stated in this report and must train at least two members of the family at the time of installation.

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 Shawdesh 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 Ferric Sulphate Employed for Coagulation

Ferric sulphate employed in this technology has a direct relevance to health and wellbeing of the technology end-users. Therefore, it is important tha:

- A) *Ferric sulphate employed Shawdesh should be analytical or reagent and obtained from a source or sources with known reputations for quality chemicals and quality controls,*
- B) *A copy of the sample analysis from the manufacturer should be attached to the ferric sulphate scathe container,*
- C) *A copy of the MSDS for all chemicals should be provided to the prospective customers,*
- D) *Chlorine solution to be used by the proponent should be specifically manufactured for potable water.*

7.2.3 Backwashing

The technology works best and produces arsenic-safe water if it is maintained well

1. After treating each batch, the bucket should be washed to remove sludge. The sand media should be washed with water thoroughly at least two times a week.
2. The backwash water should be stored for a day, the supernatant separated and discarded afterwards, and the sludge is collected and disposed, by the technology proponent/provider, following the conditions stated in 7.2.1 above.

7.2.4 Hygiene Practices

Treated water from SAF 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 and store treated water are not cleaned and disinfected before collecting water. It is important that

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 unit and in case of washing the sand and/or media.
2. The pots, pans, buckets and Kolshis 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 Chlo-tech solution or bleach powder to the water, mix it well, swirl it around a number of times and throw it away; and finally rinse the them with clean water.

7.2.5 Technology Users Support Systems

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

2. **Technology Distribution System:** Any technology may break down at some point in its life. Repairs and spare parts will be needed. For most households, reaching the SAF vendor and acquiring replacement would be very, very difficult if not impossible altogether. A distribution office in their vicinity, a store acting as an agent for the vendor, or any such facilities located in the town shopping centre or

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within a convenient distance would be very useful. If these facilities were available in the immediate vicinity, then SAF 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, SAF Proponent ought and should stock-up spare parts and supply them to distribution offices, vendors, etc.