Draft Review of the Household Arsenic Removal Technology Options

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Introduction

Arsenic is widely distributed element in the earth's crust and ranks twentieth in elemental presence. As a Group V element, arsenic exhibits a broad range of chemical reactivity and it is commercially used in alloys with lead. Arsenic in natural water has been reported from several countries including Bangladesh, China, Chile, Ghana, India, Nepal, Rumania, Taiwan, USA and Vietnam. In India, arsenic pollution is mostly of geological origin. However, ground water pollution of anthropogenic origin - due to industrial or mining waste - has been reported from Chennai in Tamil Nadu and Rajnandgaon in Madhya Pradesh.

In groundwater, arsenic occurs mainly in two forms namely arsenite [As (III)] and arsenate [As(V)]. As (III) is 60 times more toxic[1] than As(V). Clinical manifestations of long term ingestion of high arsenic water include hyperkeratosis and hyperpigmentation of palms and soles, and arsenical dermatosis. It can also result in skin, liver, lung, kidney and bladder cancer.

Due to its carcinogenic property, regulatory agencies have been constantly reviewing its maximum permissible limit (MPL). The current World Health Organization guideline value for arsenic is 10 ppb. The Bureau of Indian Standards specifies 50 ppb as the MPL for arsenic in drinking water. Considering that water consumption in tropical country like India is much higher, the current MPL of arsenic will need to be lowered.

In India, 68 block in eight districts in West Bengal with a population of nearly 5 million have reported presence of excess arsenic in groundwater – a source of drinking water for over 90% population living in rural areas. Several initiatives have been taken by the Government of India, Government of West Bengal (GoWB), research institutions, NGOs and donor agencies to implement arsenic mitigation measures. One such

[1] British Geological Survey technical report no WD/92/39

initiative is the GoWB-UNICEF Joint Plan of Action to Address Arsenic Contamination of Drinking Water.

In villages where most groundwater sources are polluted by high arsenic, it will be essential to provide alternate water supply options. These options may include use of a distant safe source, drilling of a deep tubewell to exploit deeper aquifer, roof based rain water harvesting, roughing filter combined with slow sand filtration to use pond water, use of pond water after filtration and boiling or chlorination and arsenic removal plants (community or household). *This desk review covers the currently available household based arsenic removal technologies including construction, treatment process, performance, O&M, capital and recurring costs, user friendliness and sustainability in rural areas.*

Water Treatment Options

The following arsenic removal methods have been adopted to remove arsenic from drinking water under laboratory and field conditions.

- Oxidation and stripping;
- Coagulation, precipitation and filtration using iron and aluminum salts;
- Lime softening
- ion exchange;
- Membrane processes; and
- adsorption on activated alumina / activated carbon / activated bauxite/ferric hydroxides.

The following Tables 1, 2 and 3 indicate the comparative performance of different treatment methods.

Table 1
Effectiveness of water treatment processes for removal of As(III) and As(V)[2]

Treatment method	As(III)	As(V)
Aeration and stripping	P	P
Coagulation, precipitation and filtration	F-G	G-E
Lime softening	F-G	G-E
Ion exchange		
Anion	G-E	G-E
Cation	P	P
Membrane Processes		

[2] Viraraghvan,T., Subramaniam, K.S., and Swaminathan, T. V., - Drinking water without arsenic: A review of treatment technologies, March 1996, ENSIC, Asian Institute of Technology, Bangkok

Reverse Osmosis	F-G	G-E
Electrodialysis	F-G	G-E
Chemical oxidation and disinfection	P	P
Adsorption		
Granulated Activated Carbon	F-G	F-G
Powdered Activated Carbon	P-F	P-F
Activated Alumina	G-E	E

P = Poor; F – Fair; G = Good and E = Excellent

Table 2

Treatment technologies for the removal of arsenic and their relative treatment Costs[1] in community treatment plants

Arsenic species	Treatment method	Percentage removal	Relative treatment cost (US Cents/1000gallons) 0.3 mgd	1.0 mgd	50 mgd
As(V) (Arsenate)	Alum coagulation/filtration, pH 6-7	>90	175	44	19
	Iron coagulation / filtration, pH 6-8	>90	175	44	19
	Excess lime softening	>90	305	63	40
	Activated alumina, pH 5-6	>95	122	62	51
	Ion exchange	<90	83	51	42
	Reverse osmosis	<90	332	164	129

Note : For As(III removal, oxidation treatment of As(III) to As(V) is required

Table 3 – General Performance of Activated Alumina, Strong Base Resin, Reverse Osmosis and Electrodialysis[1]

Treatment Type	Material	PH	Removal As(III)	As(V)
Packed Beds	Activated Alumina	5.5-7.5	F-P	G
	Strong Base Resin	5-9	P	P-G
Reverse Osmosis	Cellulose Acetate/ aromatic ployamide membranes	6-8	40-80%	> 80%
Electrodialysis	-	6-8	40-80%	> 80%

G = Good: Ion is highly preferred relative to Cl^-

F = Fair: Ion is preferred relative to Cl^-
P = Poor: Ion is not preferred ion relative to Cl^-

Costs, reliability and simplicity of O&M are three major factors that influence the selection of a treatment system for arsenic removal in rural areas. Reverse osmosis requires special membrane and water under high pressure and therefore not practicable at the rural household level in India. Performance data available on the ion exchange system that could be adopted in a rural household is not adequate to make an objective review. However, it is well known that water with TDS>500 mg/L – most common in groundwater – makes ion exchange process uneconomical as most of the available adsorption sites will be occupied by other competing ions and saturation point will be reached very early. At the rural household level, coagulation and precipitation and adsorption processes are considered more feasible. These technologies along with other unconventional technologies are discussed in this paper.

Coagulation, precipitation and filtration

Coagulation is one of the most conventional processes used for the removal of arsenic from water. Various studies carried out on As(III) and As(V) removal using alum and ferric salts as coagulants indicate that:

(i) More than 90% removal of arsenic (300 ppb) can be achieved by application of alum at pH < 7, ferric chloride at pH < 8.5 or by lime softening pH > 10.5
(ii) At Arsenic (V) concentrations < 1000 ppb, the coagulation with 30 mg/L of either alum or ferric sulfate results in > 90% removal of arsenic. At As(V) concentrations > 1000 ppb, ferric sulphate [$Fe_2(SO_4)_3$] was found to be better than aluminum sulfate.
(iii) Ferric chloride was more effective than alum for removal of arsenic from groundwater. In general, 30 mg/L of ferric chloride[3] ($FeCl_3$) is considered equivalent to 100 mg/L of alum $Al_2(SO_4)_3 \cdot 18H_2O$.
(iv) As(III) will need to be oxidized to As(V) by adding suitable dose of chlorine or $KMnO_4$ or H_2O_2
(v) Effectiveness of oxidants for the simultaneous removal of As(III) and iron is $KmnO_4 > O_3 > NaOCl > O_2$
(vi) While using alum, care should be taken to ensure that residual aluminum in treated water does not exceed 200 ppb – the current WHO guideline value. The Bureau of Indian Standards has specified 30 ppb as the desirable limit for aluminium. This low level of aluminium will be difficult to maintain in treated water if aluminium salts are used as coagulant. In most cases filtration through a sand filter will be necessary to reduce the risk of residual aluminium in treated water.

Environmental Protection Agency of USA has summarized coagulation with iron and aluminum salts, and lime softening as the most effective treatment processes for removing arsenic from water to meet the maximum permissible limit (MPL) of 50 ppb.

[3] ITN, Bangladesh lecture note on Arsenic Avoidance & Dearsenation of Water, Eli Dahi, May 1997

Oxidation of As III to As V followed by coagulation, precipitation and filtration is recommended. Though, coagulation is a popular method for arsenic removal, it suffers from problems of sludge disposal.

Activated alumina based technology

Activated Alumina (AA) has been frequently used for removal of cations and anions such as arsenic, fluoride, chromium, zinc, iron, phosphates and organic materials from contaminated water supplies. AA is formed by the thermal hydration of aluminum hydroxides. It has high surface area (> 200 m^2 per gram) and highly porous. The term activated refers to the capacity of alumina to enter into adsorption and/or catalytic reactions.

This treatment process has been used in USA extensively in large-scale community plants for many decades. The following table gives arsenic removal characteristics of AA in large-scale treatment plants.

Table 4 - Arsenic removal by Activated Alumina Treatment[1]

Arsenic species	Initial conc. Ppb	Removal (%)	PH
As(V)	5000	>99	6.9
As(V)	10000	99	6.8
As(III)	500	89	8.47
As(III)	1000	83	8.04
As(III)	2000	79	8.20
As(V)	2400	100	6.8

It may be noted from the Table 4 that arsenic removal efficiency for both As(III) and As(V) with raw water pH 6.8 is excellent. The Table 3 indicates that even in the wider pH range (5.5-7.5) arsenic removal efficiency of AA is good.

In AA based arsenic removal technologies the following points are important to remember:

- High iron content feed water clogs the alumina bed very quickly and makes it non-operation
- Pre-oxidation and pre-settling increases BV significantly
- High TDS can reduce AA capacity to remove arsenic
- High turbidity interferes with oxidation process and reduces AS(III) removal efficiency significantly
- For removal of AS(V), AA is most effective at pH value of 5.5
- Effective bed contact time (EBCT) of minimum 4 minutes is necessary when pH is optimum. At higher pH, BCT will be need to be increased.
- Finer grain size AA has higher arsenic removal capacity

- AA can be regenerated by treating it with NaOH (4%) and 0.5N HCl solution.
- Pre-chlorination of raw water helps in increasing capacity of AA to treat water. As against 23,000 BV[2] of pre-chlorinated water only 300 BV of 100 ppb water could be treated with MPL of 50 ppb arsenic.

In West Bengal the groundwater contains both As(III) and As(V) and therefore it is necessary to adopt a treatment process that removes both the species of arsenic. The pH and redox conditions are important factors that influence arsenic spaciation. As(V) will be predominant in aerobic surface water, whereas As(III) will be predominant in anaerobic ground water. As(III) is more soluble and therefore has to be converted into As(V) by oxidation process for its effective removal. However the studies at the Bengal Engineering College (BEC) indicate that As(III) can be removed effectively by AA bed without oxidizing it into As(V).

Assessment of arsenic removal technologies

The following arsenic removal technologies below.

i. WHO-SEARO instructions for arsenic removal
ii. DANIDA-DPHE arsenic removal unit in Bangladesh
iii. RKM Filter in West Bengal in India
iv. CMRI Filter
v. JU-CSIR Filter
vi. AMAL filter
vii. Pal Trockner
viii. Safi Filter
ix. Three-kolshi filter

I. WHO-SEARO Instructions for Arsenic Removal

This household treatment[4] is based on the well-known arsenic removal technology of oxidation of As(III) to As(V) followed by coagulation and precipitation.

Construction: The apparatus includes a 12-litre bucket (plastic/GI/SS) with a lid and fitted with a tap 50 mm above the bottom.

Treatment Procedure: Steps for treating water containing arsenic concentration of 100 to 1500 ppb are as follows:
- Take 12 L of water in a clean bucket fitted with a tap 50 mm from the bottom
- Add 2 gm bleaching powder [$Ca(OCl)_2$] with 30% chlorine
- Add 0.2 gm ferric chloride ($FeCl_3$)
- Add 7 gm fly ash for faster settling
- Stir vigorously for five minutes
- Stir again vigorously after one hour

[4] WHO-SEARO instructions, Arsenic removal by bucket treatment method, April 1997

- Allow it to settle for overnight
- Decant water and ensure that sludge is not disturbed
- Dispose the sludge by mixing it with 200 gm of cowdung

Each chemical (alum, fly ash and bleaching powder) packed separately in a sealed plastic pouch for treating 12 liters of water. The chemicals should be of good quality and free from impurities. Proper packaging and storage, particularly of bleaching powder – having a very limited shelf life say 2 months - is very important.

Performance data: No laboratory and field performance data is available for review.

Costs: The cost of chemical will be less than Rs. 0.75 per 12 L of water.

II. DANIDA-DPHE Arsenic Removal Unit

This household treatment unit[5] is based on the well known arsenic removal technology of oxidation of As (III) to As (V) followed by coagulation, precipitation and filtration.

Construction: . The components required for assembling a unit includes the following:

- 20 L plastic bucket (one red and one green)	- 2 Nos
- plastic taps	- 2 Nos.
- plastic funnel+nipple+elbow	- 1 set
- 250 mm long ½" PVC pipe	- 1 No.
- Coarse sand	- 5 Kg
- Flat metallic cover for lower bucket	- 1 No.
- Stirring rod (PVC rod)	- 1 No.

It comprises of two 20L plastic bucket placed over each other, with upper bucket covered with a plastic lid. The upper bucket (red in colour) is fitted with a tap 50 mm from the bottom. The lower bucket (green in colour) is fitted with a tap 50 mm from the bottom and a PVC pipe, a funnel and nipple joined together and connected 50 mm below the top end. The lower bucket is filled with 5 kg of coarse sand

Treatment Procedure: The procedure is simple and comprises of the following steps.

- Add 4 g of alum and 0.03 g of potassium permanganate ($KMnO_4$) in 20 L of raw water.
- Stir briskly for 20[6] times
- The pH should be between 6.5-8 for optimal coagulation, flocculation and sedimentation
- Allow the water to settle for three hours
- Decant water through the tap and funnel to the lower bucket
- Draw water from the tap in the lower bucket

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[5] DPHE-DANIDA Urban Water & Sanitation Project, Dhaka – Arsenic removal at household level, 1999
[6] Arsenic 2000 – An overview of arsenic issues in Bangladesh, December 2000, Elizabeth M Jones, Water Aid, December 2000

Performance data: Raw groundwater with arsenic level 160 –1100 ppb was treated using the above procedure. The treated water arsenic level did not exceed 20 ppb in some reported studies. However, Dhaka Community Hospital[7], Dhaka reports that the filter failed to remove higher concentration of arsenic effectively. It is reported that due to concerns of residual aluminium this filter was included in their field evaluation of treatment technologies.

Costs: The cost of filter is Taka[8] 350. The cost of chemicals for 20 litre water is approximately Taka 1.5.

Strengths and Weaknesses: The capital as well as operation and maintenance costs are low. It removes 70-90% arsenic. Unless alum is completely hydrolysed and fully precipitated, there is a possibility of residual aluminium[9] in treated water.

III. RKM Filter

It is also based on the well-known arsenic removal technology of oxidation of As(III) to As(V) followed by coagulation and precipitation. It is hybrid of DANIDA-DPHE filter used in Bangladesh and ceramic filter design.

Construction: It comprises of a bucket and two clay pitchers – one of them fitted with "Tripura filter – a low cost earthen replica of ceramic filter.

Treatment Procedure: Ferric alum and bleaching powder are required for treating water. The procedure involved in the treatment process is as follows.

- Mix ferric alum and bleaching powder in 10 L water in a plastic bucket.
- Mix well and allow the water to rest for 2 hours. Decant top 7 L of water with out disturbing sludge.
- Pour this 7 L water into the top pitcher containing "Tripura Filter".
- Collect treated water in the bottom pitcher

Performance data: It can treat 40-50 liters of water per day. Specific performance data is not available.

Costs: The capital cost is Rs. 250 per household. The operation cost is Rs. 0.75-1.00 per 10-L of treated water.

[7] Report on Action Research on Community Based Arsenic Mitigation Project, DCH, August 2000
[8] Taka – exchange rate for Bangladeshi Taka 1 US$ = 50 Taka
[9] Rapid assessment of household arsenic removal technologies Phase I, prepared for BAMWSP/DFID/Water Aid by WSAtkins, January 2001

IV. CMRI Filter

This filter is developed by the Central Mining Research Institute (CMRI), Dhanbad. It is based on the well-known arsenic removal technology of oxidation of As(III) to As(V) followed by coagulation and precipitation.

Construction: It comprises of two containers (plastic/stainless steel) each of 10-liter capacity. The upper container has a lid and fitted with a candle filter. The bottom container is fitted with a tap 25 mm above the bottom end.

Treatment Procedure: The procedure involves the following steps:

- Add one capsule in 10 litre water;
- Stir well;
- Allow the water to rest for one hour;
- Pass the water through a candle filter or 200 mm sand bed

The chemicals (a mixture of two chemical) weighing 0.6 g is packed in a capsule. The chemical composition has not been made public by CMRI. It appears that CMRI have filed a patent application for this process.

Performance data: As per the laboratory results obtained, the arsenic level in treated water comes down from 0.3 mg/L to well below 0.05 mg/L. No field test results are available.

Costs: The cost of reagents is 10 paisa for treating 10 L of water. When produced in the form of a capsule it may cost Rs.[10] 0.25 for treating 10 L water with high arsenic. Cost of chemicals inclusive of packaging and marketing per 20L of water is Rs. 0.75 to Rs 1.00.

V. JU-CSIR Filter

This household treatment unit is based on the well known arsenic removal technology of oxidation of As (III) to As (V) followed by coagulation, precipitation and filtration.

Construction: The treatment unit includes the following.
20-litre plastic or stainless steel container with lid and a candle filter (made from fly ash) fitted in the bottom. 1 No.
20-litre container (plastic/stainless steel/earthen) fitted with a tap 1 No.

Treatment Procedure:

- Put 20 liter water in upper container
- Put a tablet made of chemicals (charcoal, ferric chloride and a salt of hypochlorous acid)

[10] Rs. – India rupee, approximate exchange rate 1 US$ = Rs. 46.50

• Mix slowly till the tablet is completely dissolved
• Allow two hours for settling and filtration.
• Decant treated water through the tap.

The water is filtered through a candle specially made from fly ash.

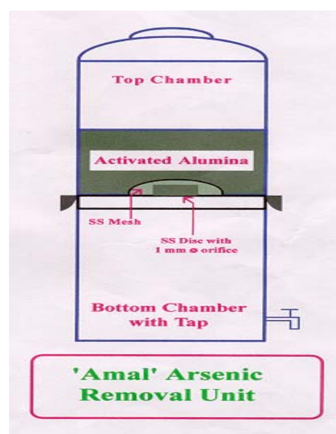
Performance data: In 3266 treated water samples analysed, only in 2730 samples[11] arsenic level was within the permissible limit (50 ppb). In some cases the tablet system was not found effective even when arsenic concentration in raw water was less than 1500 ppb. The arsenic removal efficiency varied from 74% to 93.5%. When ever arsenic concentration in raw water was more than 1500 ppb, the tablet was found ineffective as treated water never exhibited arsenic concentration 50 ppb and below. The tablet system worked satisfactorily in most cases when arsenic concentration in raw water was below 1500 ppb.

Costs: The cost of unit varies from Rs.100 – 1500. It depends on material of construction of containers. The cost of tablet is approximately Rs. 0.50 – 0.75.

Strengths and weaknesses: It is a simple and affordable option. This filter removes 74-93% arsenic. However, the performance can deteriorate if maintenance of filter, periodical cleaning of filter candle and correct methodology is not followed.

VI. AMAL Domestic Filter

The Bengal Engineering College (BEC) have developed a AA-based domestic arsenic removal unit known as "AMAL Filter" – named in the memory of late Dr. Amal K Datta who initiated its development. It is based on the principle of adsorption of arsenic ions on activated alumina surface.



Construction: It comprises a lower chamber and an upper chamber. The upper chamber (12 L capacity) contains 2.75 L of 0.4-1 mm particle size granular AA), a micro-filter (slit size < 0.2 mm) with a 1.5 mm hole to regulate flow rate (8-10 L/H). The lower chamber (12L capacity) stores treated water, which can be drawn through a tap.

Treatment process: Raw water is put in to the upper container. Arsenic gets adsorbed by porous surface of AA granules placed in the upper container. The micro-filter controls the flow rate and ensures sufficient bed contact time. The filtered water gets collected in the bottom container. AA gets exhausted after a certain time and will need to be regenerated periodically. The periodicity will depend on the chemical composition of raw water and allowable maximum permissible limit of arsenic in

[11] Evaluation of filter tablet system developed by School of Environment Studies, Jadhavpur university and CSIR for dearsenification of ground water, July 2000

treated water. The regeneration is done by dipping exhausted AA in 4% NaOH solution followed by rinsing in clean water, dipping in 0.5N HCl solution and rinsing in water till rinse water attains a pH value of (7-8).

Performance data: The Annex II and III provide graphical representation of the performance of AA-based household arsenic removal unit. The arsenic level in raw water was 0.17 – 0.27 mg/L. During the first cycle, the unit (containing 2.75 L of AA) produced 11,800[12] liters of water with arsenic level below MCL i.e. 0.05 mg/L. After regeneration of the AA, the unit in the second cycle produced well above 13,000 L of treated water with arsenic contamination below 50 ppb. In a study[13] conducted by Central Ground Water Board during August-December 2000 it was noticed that in 30 treated water samples drawn from Amal domestic filter, arsenic was below 50 ppb in 28 samples. The raw water arsenic range was 21-410 ppb.

Costs: The cost of a domestic AA-based arsenic removal unit varies from Rs.700 to Rs. 1,500 depending upon the material of construction. A community plant may cost Rs.15,000. AA costs Rs. 100 (US$ 2.25) per kg and it can be regenerated several times. AA regeneration cost is nearly Rs.50 per household per annum.

Strengths and Weakness: It is very simple to operate and very attractive to users. It is also technically very effective. The capital and operation costs are high when compared with Three-kolshi Filter or Safi Filter. Unless regeneration of media (using acid and alkali) is done, its replacement is expensive. High iron bearing water can cause clogging of filter requiring frequent washing of media. Poor quality AA can adversely affect the performance and increase the risk of unacceptable level of residual aluminium in treated water.

VII. Safi Filter

Construction: The safi filter comprises of two concrete buckets of different sizes, one of which is placed above the other. The upper bucket is fitted with the Safi candle (made from chemical mixture of laterite soil, ferric oxide, manganese di-oxide, aluminium hydroxide and mezoporous silica). Raw water in the upper bucket passes through the candle and gets collected in the lower bucket. The permeable candle adsorbs arsenic and removes bacteria. As per manufacturer, a household of five members can use the candle for two years.

Treatment process: Arsenic is absorbed on candle material[13] when raw water passes through candle.

[12] Datta, Amal K., Gupta, Anirban 1997 – Genesis of the arsenic problem, status and alternatives for remediation, Bengal Engineering College, Calcutta, India

[13] Evaluation of performance of various arsenic removal equipments installed in arsenic infested area of West Bengal, by Central Ground Water Board, March 2001

Performance: During field tests it was observed that the candle gets clogged[14] resulting in significantly reduced flow rates and candle life - less than two months. More over, it was not effective in the removal of arsenic to ensure sustained supply of drinking water within the permissible arsenic limit. None of the filters, at any stage of operation, provided bacteria free water. It appears that further development work is in progress to over come the above weaknesses.

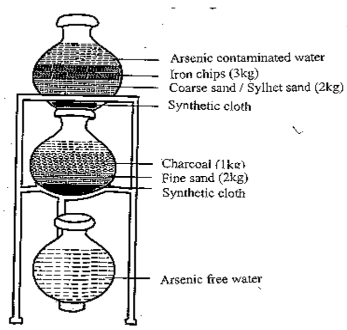
Costs: The cost of the 40 L per day filter is Tk 900 (US$ 18) . The cost of candle is Tk. 200 which has to replaced every two months.

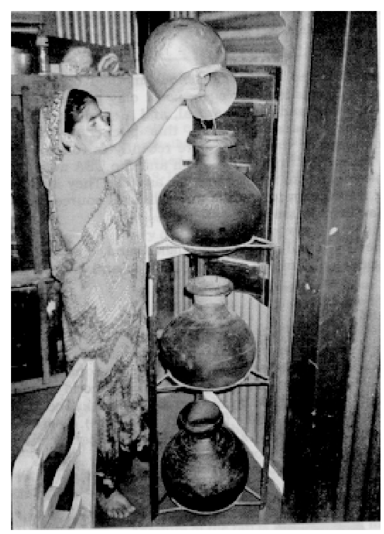
Strengths and Weaknesses: Cost is affordable for many rural households. Due it's resemblance with candle type filter, people tend to prefer it as they can use the nearby tubewell water. Many filter were out of use due to problems such as disintegration of filter candle, breaking of taps, clogging of filter, terribly low filtration rate and reduction in its arsenic removal capacity after usage for two months.

Overall Assessment: It has potential for large-scale application but only after some more development work to remove problems.

VIII. Three-kolshi or Three-pitcher Filter

This filter is based on the age-old indigenous method of filtration





Construction: It consists of three 18-liter clay pitchers[11] stacked one on top of the other. The top pitcher contains 2 kg. of coarse sand and three kg of iron filings on the top. The middle pitcher contains a layer of synthetic cloth to prevent sand on which 2 kgs.of coarse sand and one kg of charcoal are placed. The third pitcher is for collecting the filtered water. Top and the middle pitcher have some small holes in the bottom to facilitate draining of water from one pitcher to other. A steel frame is used to support middle and top pitchers. The flow rate is 1.2-2.9 L/hr.

Treatment Procedure: It relies on passive coagulation with iron filings and/or adsorption to sand matrix and filtration.

[14] BRAC report, Combating a deadly menace – Early experiences with a community-based arsenic project, August 2000

Performance: During the first six weeks over 80% - 92 % filters were effective in reducing arsenic and iron. On an average reduction in arsenic was from 240 ppb to 18 ppb (see Table 5)[13]. The observed decrease in iron was 0.87 ppm to 0.012 ppm. The total coliform count in 25 filtered water is given in Table 6. The treated water was reasonably free from bacteria. By 13th week only 65% filters were effective. After four months of continuous operation the three-pitcher filters showed some problems in terms of leaching of arsenic and clogging in iron fillings. In some case it was found that iron filings were clogged forming a hard structure which could not be removed from the pitcher. In such cases the pitcher with sand and iron filling was discarded and replaced with new pitcher.

Table 5 Level of Arsenic and Iron in Raw Water and Treated Water[13]

SAMPLE SOURCE	As (ppb)		Fe (ppm)	
	Before treatment	**After treatment**	**Before treatment**	**After treatment**
3-Kolshi filter 1	335	28	1.556	0.014
3-Kolshi Filter 2	5	5	0.529	0.017
3-Kolshi filter 3	195	20	0.495	0.022
3-Kolshi Filter 4	388.2	10	2.041	0.012
3-Kolshi Filter 5	232	31	1.249	0.019
3-Kolshi Filter 6	312	7	1.772	0.014
3-Kolshi Filter 7	81	24	0.110	0.009
3-Kolshi Filter 8	295	25	0.877	0.004
3-Kolshi Filter 9	318	12	0.141	0.001
3-Kolshi Filter 10	233.9	17	1.098	0.006
Average	240	18	0.877	0.012
Maximum	5	5	0.110	0.001
Maximum	388.2	31	2.041	0.019

Table 6 – Total and Faecal Coliform after Filtration by Three Kolshi Filter [13]

Coliform type	Number of filters tested	Coliform load (cfu/100ml)		Range cfu/100 ml
		Mean	Median	
Total	25 (22/02/00)	26.20	13	0-94
Faecal	25 (22/02/00)	4.16	1	0-27
Total	25 (07/03/00)	4.24	4	0-10
Faecal	25 (07/03/00)	0.92	0	0-4

As sand, charcoal, iron filings, synthetic cloth and clay pitcher are easily available, it is easier for people to adopt this technology.

Costs: The cost is Taka 250 (US $ 5) – Tk. 170 for steel stand, Tk. 30 for three clay pitchers and Tk. 50 for sand, charcoal, synthetic cloth pieces and sand.

Strengths and weaknesses: The three-pitcher filter is inexpensive and easy to assemble with locally available materials. It is based on an indigenous technology known to people from several decades. Use of tubewell water means less risk of microbial pollution. There is a potential problem of clogging with iron, particularly if the filter is allowed to dry out between uses. Iron filings tend to form bond together to form solid mass making cleaning or replacement of difficult. After four months of use, problems of leaching of arsenic and clogging of iron were noticed.

The three-kolshi filter is inexpensive and has enormous potential for use. However, it requires further studies on the occurrence of microbial contamination and leaching of arsenic from spent iron filings are required.

IX. Paul Trockner

The filter is based on adsorption technique for arsenic removal. Granular ferric hydroxide reactor are fixed bed absorbers[12] operating like conventional filters with a downward water flow. It is poorly crystallized β FeOOH with a specific surface area of 250-300 m^2 / g and porosity of 75-80%. The grain size varies from 0.2-2 mm. It is expected to yield much higher removal capacity for adsorption of arsenic from water than activate alumina. Some studies indicate that ferric hydroxide has 3 to 10 times higher efficiency than activate alumina for adsorption of both AsIII and AsV.

Construction: It consists of a cylinder filled with grannular feric hydroxide with inlet and outlet connections. It requires a small of head of water, say 1 meters, to operate satisfactorily.

Performance: Ten domestic filters were field tested for a period of six months in West Bengal. Out of 30 treated water samples collected, 29 sample had arsenic below 50 ppb. Arsenic in raw water varied from 30 ppb to 2950 ppb. During the test period all the ten units performed satisfactorily.

Costs: The unit cost is Indian Ruppees 4500.00 which is considered unaffordable by most villagers. O&M costs are not available.

Strengths and Weaknesses: It appears to be a technology with potential for use. However, costs are high are beyond the reach of most rural habitants. The unit need to be observed over a period of at least two years to check if it posses operational problems.

This technology has good potential for large-scale use. However, long tems monitoring of these units is necessary before a decision could be taken on its suitability.

Disposal of Sludge from Arsenic Removal Units

In coagulation and sedimentation process arsenic rich sludge is produced. Similarly spent regenerants from a AA regeneration unit will also contain high arsenic. It is therefore necessary to ensure that this highly toxic effluent/sludge is disposed off safely to eliminate environmental hazards.

In rural households the sludge from domestic arsenic removal units can be disposed off after mixing it with 200 g of cow-dung. The microorganisms in cow dung transform arsenic to gaseous arsine and arsenic is thus released in to atmosphere. It can be then be disposed in an unlined pit 10-M away from a drinking water safe.

BCE has reported that the alkali and acid effluent from a regeneration unit when mixed together produces an effluent of 7.0 pH. This results in the settlement of most aluminium and ferric hydroxide flocs. The supernatant is considered of acceptable quality for disposal. The available literature indicates that the dried arsenic rich sludge (10% by weight) when mixed with 1:4 cement mortar can be stabilized satisfactorily. Leachate tests conducted (pH 5 +/- 0.5 and 1N acetic acid) on cement blocks produced leachate with arsenic below detection limit. More studies are needed on safe disposal of arsenic rich sludge and effluent. This aspect should be considered carefully while selecting an arsenic removal technology.

Conclusions:

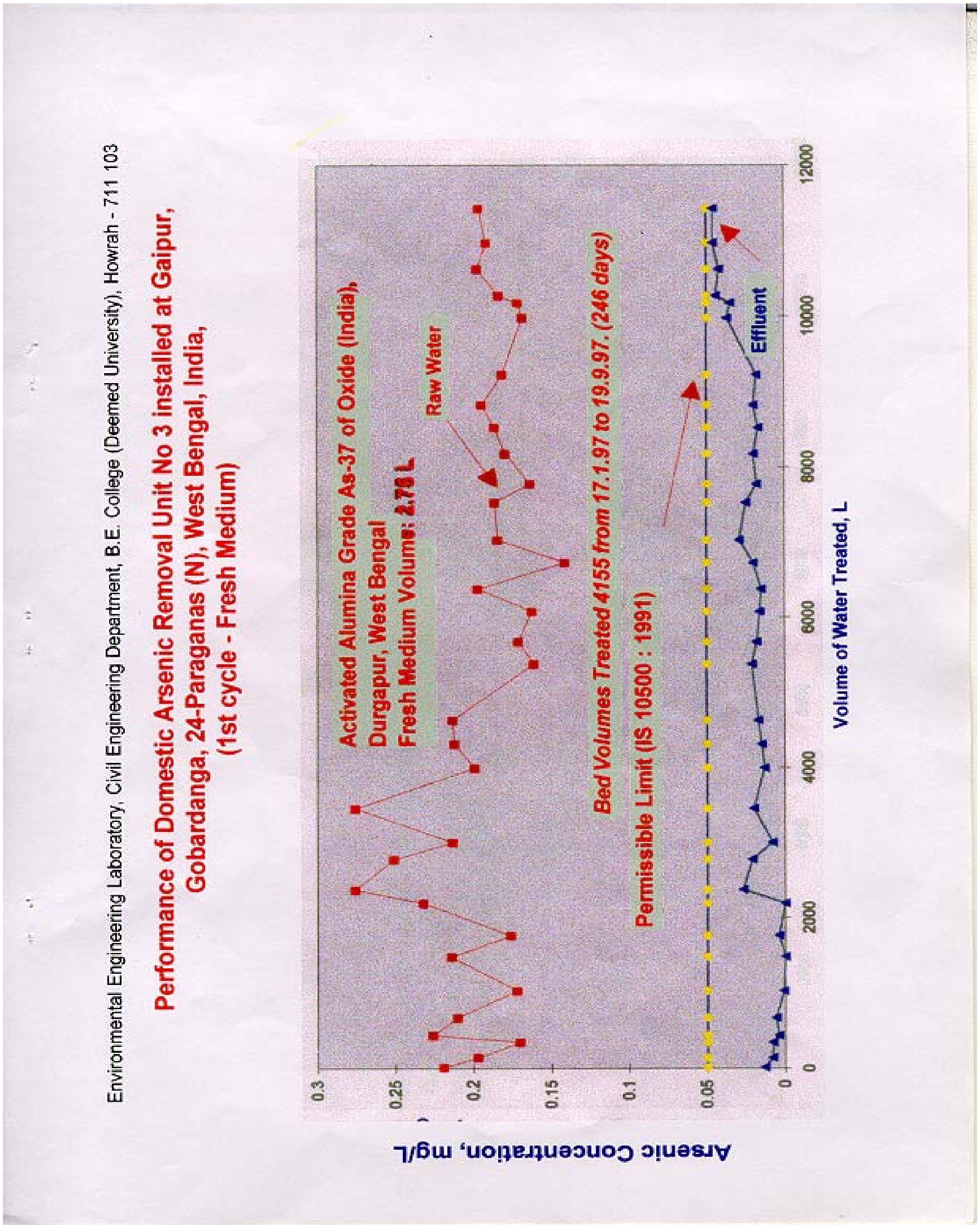
The broad conclusions are as under.

1. The Annex I provides a comparative analysis of household arsenic filters either under field testing in Bangladesh or India..
2. The capital cost, O&M costs, ease of O&M, local availability of chemicals and willingness of users to pay for O&M fully are some of the important factors for selecting an appropriate technology and to ensure sustainability.
3. The listing of technologies in this note does not mean that they are safe technologies to use or they remove arsenic consistently below 50 ppb. The above information should be used as an initial information point to seek further details from developers and manufacturers and organizations that have carried out long term tests on these technologies. A technology that works successfully in a certain field environment may not be successful in the other. Therefore, technology selection should be done very carefully and tried on a pilot scale in local field conditions to assess its suitability.
4. In coagulation, precipitation and filtration process, it is necessary to take precautions so that flocs do not escape in treated water. The technologies that fall under this category are CMRI, Dhandad in India, DANIDA-DPHE Filter in Bangladesh, RKM filter in West Bengal, JU-CSIR and WHO recommendation on the use of alum, fly ash and bleaching powder. When aluminium salts are used care should be taken to ensure that free residual aluminum is not present in treated water. As per Bureau of Indian Standards specification on drinking water, aluminium in excess of 30 ppb can cause dementia. However, WHO guideline value for aluminium is 200 ppb. In case aluminium salts are used it is recommended that treated water be passed through a slow sand filter bed (600-

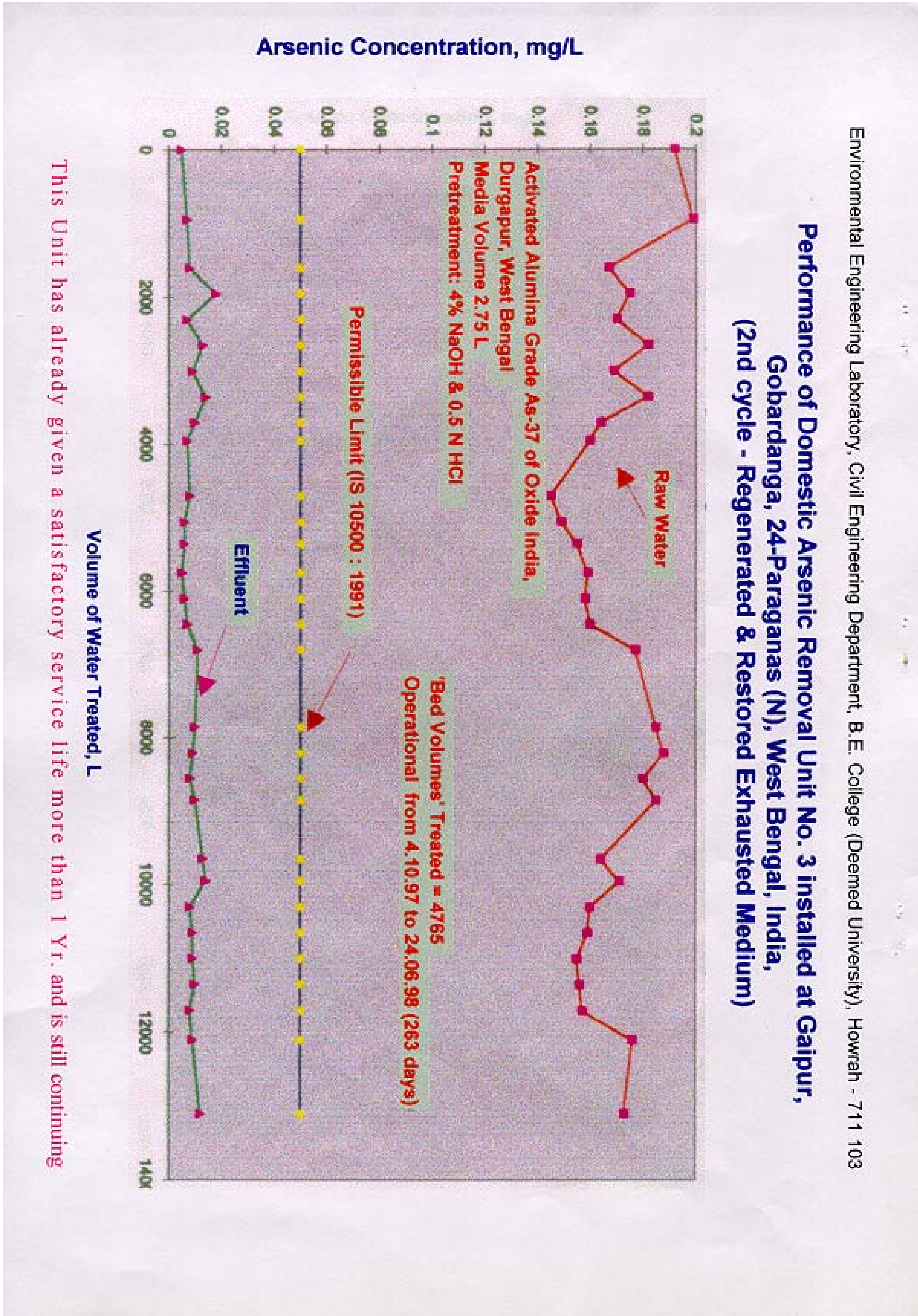
750 height) to minimize the risk of residual aluminium in treated water. Preference should be given to the use of ferric salts.

5. The AA based arsenic removal units are attractive and user friendly. However, in the absence of proper arrangements for regeneration of AA it will not be effective and replacement of exhausted AA with new AA will be a very expensive. To prevent frequent clogging due to excess iron in water, it is suggested that iron and turbidity are removed by passing raw water through “Tripura Candle Filter” or TERRACOTTA filter. This helps not only in preventing frequent clogging of AA but also in increasing its capacity to treat water.
6. Three-Kolshi filter appears to be an attractive option as it uses locally available material. It is low cost and considered sustainable in rural areas. However, more field data is needed before it could be adopted on large-scale.
7. Paul Trockner filter has performed well in limited field trails and has potential for large-scale use. However, the capital and O&M costs are not affordable by low-income communities.
8. The sludge from most treatment processes is toxic and therefore should be disposed in an environmentally friendly manner. The slug can be easily mixed in bricks or cement concrete blocks used for housing. There is a need to establish a well-defined protocol for the disposal of arsenic sludge at various levels.

Annex II


Environmental Engineering Laboratory, Civil Engineering Department, B.E. College (Deemed University), Howrah - 711 103
Performance of Domestic Arsenic Removal Unit No 3 installed at Gaipur, Gobardanga, 24-Paraganas (N), West Bengal, India, (1st cycle - Fresh Medium)
Activated Alumina Grade As-37 of Oxide (India), Durgapur, West Bengal
Fresh Medium Volume: 2.76 L
Raw Water
Bed Volumes Treated 4155 from 17.1.97 to 19.9.97. (246 days)
Permissible Limit (IS 10500 : 1991)
Effluent
Arsenic Concentration, mg/L
0.3
0.25
0.2
0.15
0.1
0.05
0
Volume of Water Treated, L
0
2000
4000
6000
8000
10000
12000

Annex III



Environmental Engineering Laboratory, Civil Engineering Department, B.E. College (Deemed University), Howrah - 711 103
Performance of Domestic Arsenic Removal Unit No. 3 installed at Gaipur, Gobardanga, 24-Paraganas (N), West Bengal, India,
(2nd cycle - Regenerated & Restored Exhausted Medium)
Arsenic Concentration, mg/L
Raw Water
Activated Alumina Grade As-37 of Oxide India, Durgapur, West Bengal
Media Volume 2.75 L
Pretreatment: 4% NaOH & 0.5 N HCl
Permissible Limit (IS 10500 : 1991)
'Bed Volumes' Treated = 4765
Operational from 4.10.97 to 24.06.98 (263 days)
Effluent
Volume of Water Treated, L
This Unit has already given a satisfactory service life more than 1 Yr. and is still continuing