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Approaches to Development of a User-Friendly Community Based Arsenic/Iron Removal Unit in Bangladesh

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Keywords

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Approaches to Development of a User-Friendly Community Based Arsenic/Iron Removal Unit in Bangladesh

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Abstract: The present study focuses on the strategies to modify the design of a community based Arsenic-Iron Removal Unit (AIRU) based on the field performance of the AIRU and the feedback from the users. The ultimate aim was to offer a user-friendly and sustainable system. Appropriate modifications in the design of the developed unit reduced the propensities of water head-loss and media clogging, thereby yielding sustained flow rate. Introduction of a simple cleaning procedure (98% flow-recovery with three successive backwashing sequences) successfully reduced the frequency of requirement of labor-intensive replacement of the whole filter media. Raw water with arsenic concentration up to 200 μg L^{-1} along with high iron content was treated by the AIRU under the field conditions satisfying the Bangladesh standard (50 μg L^{-1}) without using any chemicals. Efficient sludge management was ensured through proper drainage and safe disposal facilities. Simple construction using locally available materials, considerable treatment performance as well as ease of operation and maintenance present the developed system as a promising one.

Key words: Arsenic-iron removal, Bangladesh, flow recovery, user friendly system

INTRODUCTION

The contamination of groundwater by sediment-borne arsenic threatens the health of tens of millions of people worldwide and has taken a serious turn in Bangladesh where groundwater accounts for 97% of rural drinking water supplies and irrigation (Hossain, 2006). Diverse technologies including membrane technology (Oh *et al*., 2000), advanced oxidation process (Zaw and Emett, 2002), adsorptive filtration (Jalil and Ahmed, 2001; Leupin and Hug, 2005), ion exchange (Sutherland *et al*., 2001) and coagulation/co-precipitation followed by filtration (Wickramasinghe *et al*., 2004; Meng *et al*., 2001) have been described in literature. However, a low-cost option yielding efficient treatment along with simple operation and maintenance would be best suitable for the rural inhabitants of Bangladesh. In this context, arsenic removal by adsorption and co-precipitation with iron naturally prevalent in groundwater of Bangladesh would be a very effective technique (Ahmed, 2001). Although a few household arsenic removal units based on this principle have been developed and tested in the field, little attempt has been made in the development of a community type Arsenic-Iron Removal Unit

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(AIRU) which would allow sharing of cost and labor for maintenance of such a unit. Moreover, recent experiences adopting the technique of arsenic adsorption and co-precipitation with iron and subsequent sand filtration suggest that clogging of filter media and unmanaged sludge are the particular concerns associated with such systems (Ahmed, 2001). In this study a community based AIRU was developed adopting the technique of adsorption of arsenic onto the flocs of ferric hydroxide and subsequent co-precipitation, making use of the naturally occurring iron in groundwater. Special focus was given on the strategies to modify the developed AIRU in order to offer a user-friendly and sustainable system.

The purpose of this study was to elucidate the difficulties regarding operation and maintenance of the AIRU at the field level in Bangladesh and to modify the developed unit according to field needs. The ultimate aim was to formulate a user friendly system offering a sustainable solution to the water supply problems in arsenic and iron affected areas of Bangladesh.

MATERIALS AND METHODS

Five AIRUs, denoted as AIRU 1 to 5, were set up adjacent to five tubewells located at different field sites of acute arsenic affected areas in Jessore district of Bangladesh. Each AIRU was directly attached to a tubewell as shown in Fig. 1. Intensive field monitoring of the performance of each unit was carried out to identify the limitations in removal capacity and the difficulties regarding operation and maintenance. Modifications made in response to the performance of the installations at the field led to a design which yielded reasonable water quality while simultaneously improving the ease of operation and maintenance. In this study, the step-wise modifications that were taken for the development of a sustainable treatment unit have been highlighted. Nevertheless, the long-term field observation of this modified unit is still underway.

Unit Processes Involved in AIRU

The design specifications and the successive modifications of each AIRU have been outlined in Table 1. The AIRU mainly consisted of two chambers as shown in Fig. 2. The unit processes involved can be summarized as follows:

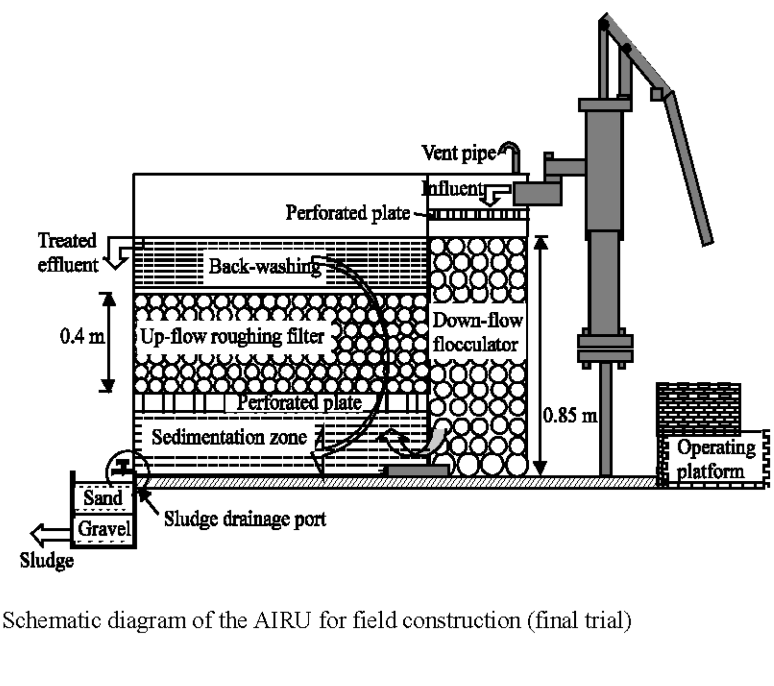

Fig. 1: Schematic diagram of the AIRU for field construction (final trial)

Table 1: Design modifications made for different AIRUs

Purpose	Activity	AIRU-1	AIRU-2	AIRU-3	AIRU-4	AIRU-5
To increase the flow	Total No. of chambers	3[a]	2	2	2	2
	Area of down-flow flocculator (m^2)	0.124	0.325	0.325	0.325	0.186[b]
	Area of up-flow roughing filter (m^2)	1.138	1.138	1.138	1.138	0.372
	Gravel size at bottom layer	Finer	Finer	Coarser	Coarser	Coarser
	Pore size of perforated slab	Smaller	Smaller	Larger	Larger	Larger
	No. of Int. connect. Pipes	3	5	5	6	6
Easy pumping	Height of operating platform (m)	0.6	0.6	0.45	0.45	0.45
Sufficient sludge drainage	No. of sludge drainage/wash out pipes at the base level	1	2	2	2	2
Controlled flow of sludge	Flow protection and control device attached with sludge drain pipe	Blind Plugs	Gate Valves	Gate Valves	Gate Valves	Gate Valves
Safe sludge disposal	Type of installation of the (unconfined/confined) sludge disposal unit	Un Conf.	Conf.	Conf.	Conf.	Conf.
Solution of pre-casting problems	Cover plate for protecting external contamination	FC-PC Slabs	FC-PC Slabs	FC-PC Slabs	FC-PC Slabs	Plastic Plate
	Perforated plate at the inlet for aeration	FC-PC Slabs	FC-PC Slabs	FC-PC Slabs	FC-PC Slabs	Plastic Plate
	Perforated slabs in the 2nd up-flow chamber for retaining the gravel	RCC PC Slabs	RCC PC Slabs	RCC PC Slabs	RCC PC Slabs	Plastic Plate

FC = Ferro-Cement, PC = Pre-Cast, R.C.C = Reinforced Cement Concrete, [a]: Additional sand filter (volume 0.17 m^3), [b]: To reduce the work-load during backwashing, which required that the unit be filled up with water by hand-pumping, a smaller sized unit was explored

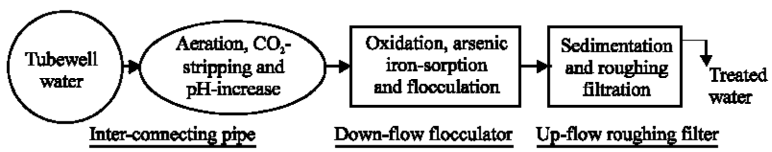

Fig. 2: Flow diagram of the unit processes of the AIRU

Inter-Connecting Pipe

The AIRU was connected to the spout of tube well with a 75 mm φ PVC pipe. Water entering the first chamber was distributed uniformly over the bed of the coarse media through a porous thin plastic plate placed on the top. This enabled strip-out of CO_2 and increase of pH, leading to oxidation of soluble iron.

Down-Flow Gravel Bed Flocculator

Iron, following oxidation, precipitated on the top and within the interstices of the coarse media (gravel bed). Arsenic, adsorbed on iron, then co-precipitated. Sinusoidal flow across the coarse media facilitated the flocculation of the precipitated particles and hence larger flocs were formed.

Up-Flow Gravel Bed Roughing Filter

Sedimentation

Comparatively larger flocculated particles settled down at the bottom of this chamber. The average detention time was around 25 min.

Roughing Filtration

Removal of the remaining flocculated particles by mechanical straining took place during up-flow through the small-grained gravel bed media in this chamber.

In addition to the above mentioned two chambers, in AIRU 1 (Table 1) an additional sand filter bed was used with a view to achieving good removal. That chamber, however, was omitted in the other AIRUs in order to avoid acute drop in hydraulic head.

Analytical Methods

Sampling And Storage

Water samples were collected from the field and tests were performed both in the field and in laboratory following standard procedures. Samples for laboratory analysis were acidified prior to their storage to avoid precipitation of iron.

Analysis Method

Field kits (HACH, USA) were used for on-site determination of arsenic and iron in the samples. Arsenic determination by HACH kit involves generation of arsine gas (AsH_3) by addition of pre-packaged sulfamic acid and zinc powder and its entrapment on a strip of paper impregnated with mercuric bromide, followed by comparison of the color of the orange-brown circle on the strip to a reference scale. Graphite furnace atomic absorption spectrometry (AAS 6800, SHIMADZU, Japan) was used for laboratory determination of Arsenic.

Questionnaire Survey Regarding the Performance of AIRUs

Beneficiaries were interviewed using a prescribed questionnaire regarding the performance (water quality and ease of operation and maintenance) of the AIRUs. The specific criteria under consideration were- color (due to iron), odor and taste, reduction in treated volume, difficulty in pumping tubewell by hand, sludge drainage and management, ease of construction.

RESULTS AND DISCUSSION

Arsenic and Iron Removal Efficiencies

Table 2 shows the overall removal efficiencies of arsenic and iron achieved by different AIRUs. Over 75% arsenic removal efficiency was achieved directly by using the AIRU without using any chemicals provided that the raw water arsenic concentration was within 200 μg L^{-1} and the iron-arsenic concentration ratio was around 30 (wt./wt.). For arsenic concentration above 200 μg L^{-1} and iron-arsenic concentration ratio less than 30, intermittent dosing of oxidizing agent was required to convert the As(III) into As(V) to ensure more adsorption of arsenic onto iron oxide surfaces and hence maintaining the arsenic content in the treated water within the acceptable limit of Bangladesh Standards (50 μg L^{-1}). This, however, led to objectionable odor in the treated effluent. Filtration through an additional commercially available sorptive media following the AIRU eliminated the requirement of an oxidizing agent. Conversely, an elongated active life of the sorptive media was observed due to major removal of arsenic and iron from raw tubewell water by the AIRU pretreatment. Appreciable iron removal efficiency was noticed from the very beginning of the commissioning of all the AIRUs. The initial iron removal efficiencies of the treatment units were around 85%. Moreover, it increased with the passage of time (over 90%) due to gradual deposition of iron flocs on surface and within the interstices of the gravel bed. In general, higher removal was associated with comparatively higher raw water iron concentration (AIRU-3,4). The AIRU-5, however, exhibited fluctuating iron removal efficiency, presumably owing to its smaller size causing higher face velocity (flow rate per unit cross-sectional area) through the media.

Ease of Operation and Maintenance

Variation of Flow of Treated Water

The variation of treated water flow as a percentage of tubewell flow with Bed Volume (BV) for different AIRUs is shown in Fig. 3.

Table 2: Raw water quality of different selected tube well sites

	Raw water quality					AIRU treated water Minimum removal (%)	
Tubewell sites	pH	Iron, Fe (mg L^{-1})	Arsenic, As (μg L^{-1})	Ratio (Fe/As)	Alkalinity as $CaCO_3$ (ppm)	As	Fe
AIRU-1	7.0	3.0	106	28.3	410	71.7	83.3
AIRU-2	7.1	5.0	160	31.2	406	80.0	88.0
AIRU-3[a]	7.1	5.0	430	11.6	414	82.5	84.0
AIRU-4[a]	6.9	4.0	480	8.3	330	75.0	82.5
AIRU-5[a]	7.0	7.0	310	22.5	390	84.5	82.8

[a]: Calcium hypochlorite was used as an oxidizing agent owing to the high As-content in raw water

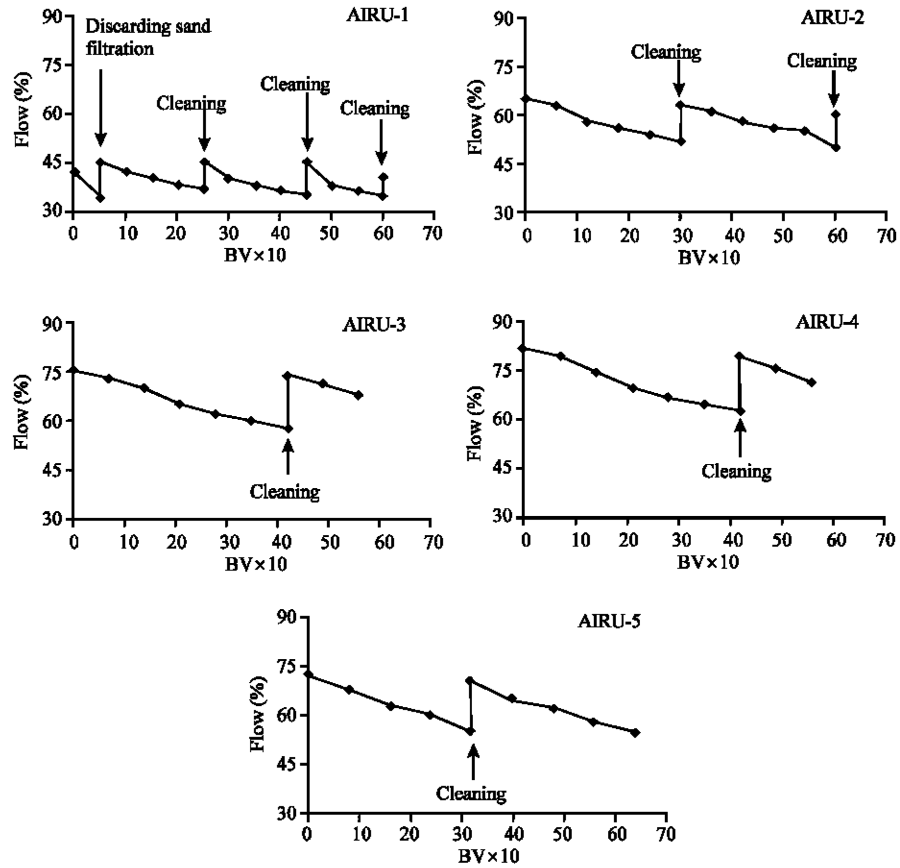

Fig. 3: Variation of Flow of Treated Water (as a % of Tubewell Flow) with Bed Volume (BV). BVs for all of the AIRUs-1, 2, 3, 4 and AIRU-5 were 735 and 305 L, respectively. Despite similar design, lower initial effluent flow and faster clogging in AIRU-5 as compared to those in AIRU-4 were due to smaller flow area and higher iron content in raw water, respectively, in case of the former unit)

The use of an additional sand filter bed at the final treatment stage of AIRU-1 with a view to achieving high removal efficiency caused an abrupt increase of head loss of water and thus the flow was restricted around 42% of the tube well water flow. Within only 70 BV of operation this flow further reduced down to 34% due to clogging. The flow could be recovered up to 45% by eliminating the sand filter bed and this caused only a negligible drop in removal efficiency of AIRU-1.

Increasing the volume of the first down flow chamber brought upon further improvement in AIRU-2. This intervention allowed reduction of head loss and, hence, an initial effluent flow of 65% of the influent flow of tubewell water was achieved. After 300 BV of operation, the flow decreased down to around 50% of influent flow. Cleaning, however, enabled almost complete recovery of the initial flow.

Additional modifications were made in the AIRU-3 by placing coarser gravel materials at the bottom layer of the down-flow flocculator and making larger holes in the perforated slab. The initial flow of the treated water from this unit was 75% of the tubewell water flow. After 420 BV of operation it reduced down to around 60%, which, then, was almost completely recovered by cleaning operation.

The number of the interconnecting pipes between the down-flow flocculator and the up-flow roughing filter were increased in the AIRU-4 to achieve further increased flow of treated water. In this case the initial treated water flow was found around 82% of the tubewell water flow. The rate of clogging of this unit was almost similar to that of the AIRU-3.

Considering the economic aspect as well as to reduce the work-load during backwashing, which required that the unit be filled up with water by hand-pumping, the fifth unit was made smaller in size. As a result, a lower initial treated water flow (around 72% of the original tube well flow) was observed. The flow of the treated effluent further reduced significantly to around 55% of the influent flow within 320 BV of filter run due to the smaller volume of media-bed and higher iron content in the raw water. This observation again underscored the necessity of maintaining an optimum face velocity. Subsequent simulation studies conducted in our laboratory revealed an optimum face velocity of 0.5 $m^3/m^2/h$.

Flow Recovery of the AIRU by Cleaning Operations

A user-friendly system implies that the frequency of cleaning should be low and the cleaning procedure should be simple as well as less labor-intensive. Step-wise modifications to the design of the AIRU were made to reduce the probability of clogging of the filter-media. In addition to that, the speciality of the developed AIRU in comparison to the previously reported community based treatment units was introduction of a cleaning procedure not requiring frequent removal of the whole of the filter media. Cleaning was simply performed by opening the gate valve at the bottom layer of the up-flow roughing filter and flushing out the settled sludge within the interstices of the gravel bed media through backwashing by hydrostatic pressure. Satisfactory flow recovery (as a % of initial flow) of the treated water from the AIRU was achieved during the cleaning operations as shown in Fig. 4. After the 1st, 2nd and 3rd flushing on the same day the flow was recovered up to 85, 95 and 98%, respectively, from the clogged condition of 50% flow from the AIRU-5. The negligible residual clogging may be attributed to the previously deposited recalcitrant iron precipitates that the applied

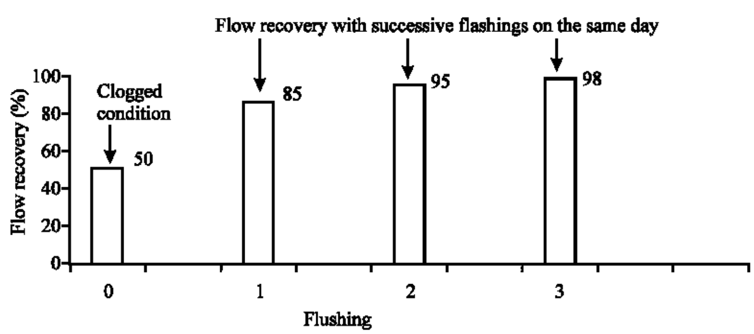

Fig. 4: Flow recovery of treated water (as a % of initial flow) with flushing

cleaning method could not washout efficiently. A limitation-common to all of the units explored and perhaps more critical in case of the AIRU-5 receiving raw water with high iron-content (Table 2), was that the applied backwashing was mainly effective in cleaning the up-flow roughing filter (Fig. 1). Since the volume of the media within the down-flow flocculator was considerably smaller than that of the media in the second chamber, the clogging in the former was expected to be not significant. However, this may not be the case for a unit fed with high iron containing raw water. Under such conditions, up-flow technique may be adopted for both the chambers. This may be simply achieved by introducing pipes connected to the bottom and placed prior to each of the chambers so that the influent from the tubewell enters the gravel bed flocculator under up-flow mode via a pipe and then enters the subsequent gravel bed roughing filter via a set of pipes, also in the up-flow mode.

Notwithstanding the probable scopes for improvement, it is worth-noting that comparatively easier cleaning operation was experienced in AIRU-5 owing to its smaller size requiring less volume of water to fill it up during backwashing. Long-term operation of the unit may eventually lead to irrecoverable clogging, which would require complete removal, intensive washing and reconstruction of the filter media. Nevertheless, the superiority of the developed system lies in the fact that the introduction of periodic simple backwashing successfully reduced the frequency of requirement of such labor-intensive renewal of whole filter media.

Beneficiaries' Opinion Regarding the Developed AIRU

The beneficiaries were found very enthusiastic in participating in the questionnaire survey. A sense of ownership of the AIRUs during their operation and maintenance developed among the users. 100% of the users felt that the water quality, particularly in terms of the presence of iron that was conceivable through its reddish color, improved dramatically. Table 3 furnishes the opinions of the beneficiaries regarding the AIRUs.

The satisfaction of the users in terms of the quality of the water produced by AIRU-(1 and 2) rooted from the fact that the raw water quality for these AIRUs was comparatively better (Table 2). As a result, for those AIRUs, the application of additional oxidant (e.g., calcium hypochlorite) was unnecessary, which, in turn, made the effluent free from obnoxious odor associated with such oxidant. The raw water arsenic concentrations were very high (around 400 ppb) in AIRU-(3, 4 and 5) and, thus, calcium hypochlorite was used as an oxidizing agent to ensure higher adsorption of arsenic on iron. This caused objectionable odor in the effluent. Accordingly, those units received unfavorable ratings from the users. Again, the iron content in the treated water from AIRU-5 fluctuated owing to the application of a high face velocity. Due to such deteriorated quality in terms of appearance and taste, the AIRU-5 failed to receive favorable response from the users.

On the other hand, the operation and maintenance (O and M) of AIRU-1 was rated to be tedious as the use of a third compartment (sand filter) in that unit caused acute reduction in flow of treated water. The users found the O and M to be comparatively easier for the subsequent AIRUs due to gradual modifications resulting in appreciable effluent flow and reduced cleaning frequency.

Table 3: Beneficiaries opinion as a percent of the total users of the AIRU(s)

		Opinions regarding water quality (%)			Opinions regarding operation and maintenance (%)		
Field sites	No. of users	Excellent	Good	Bad	Excellent	Good	Bad
AIRU-1	56	64	36	-	-	55	45
AIRU-2	82	60	40	-	21	63	16
AIRU-3	70	25	70	5	29	60	11
AIRU-4	75	32	65	3	29	62	9
AIRU-5	60	38	50	12	45	50	5

It is worth-noting that although clogging occurred slightly faster in AIRU-5 owing to the high iron and arsenic content in the raw water, the AIRU-5 received the best rating under the O and M criterion. This was because easier cleaning operation was experienced in this smaller unit requiring less volume of water to fill it up during backwashing.

In addition to mitigating the problems of flowrate reduction and clogging, some other limitations of the earlier AIRUs were rectified, as outlined in Table 1, in the subsequent units to promote their acceptance to the users. The specific reasons underlying the modifications are briefly mentioned henceforth.

Difficulty in Pumping the Tubewell

In case of AIRU (1, 2) the outlets of the adjacent tube wells and, hence, their operating platforms too, were positioned about two feet over their original locations in order to ensure gravity flow through the AIRUs that were constructed at the ground level. This, however, owing to the increase of suction head, made it more difficult to withdraw water by hand-pumping. To mitigate this problem, the base of the AIRU was placed below the ground level. This enabled utilization of a reduced operating height.

Insufficient Sludge Drainage Facility

Only one sludge drainage/wash out pipe was installed at the base level for both the down-flow and up-flow chambers in AIRU-1. This caused insufficient sludge drainage during cleaning operation. Accordingly, an additional drain pipe was introduced.

Uncontrolled Flow of Sludge

A blind plug was used as the end cap for sludge withdrawal port in AIRU-1, which caused uncontrolled flow of sludge during cleaning operation. Thus a gate valve was introduced.

Difficulty in Sludge Management

For AIRU-1, initially the sand trap along with gravel soak pit arrangement for sludge disposal (Fig. 1) was kept uncovered. This posed the risk of direct exposure of the toxic sludge to the users. Hence, a cover was introduced. It is worth-mentioning here that the periodically withdrawn sludge was disposed in cow-dung bed as earlier studies have suggested that bio-chemical (e.g., bio-methylation) process in the presence of fresh cow-dung may lead to significant elimination of arsenic from arsenic-rich treatment wastes (Ali *et al*., 2003; Bentley and Chasteen, 2002).

Difficulty in Pre-Cast Slab Construction

The main structure of the AIRU was constructed using simple brick masonry. However, Pre-Cast (PC) perforated Reinforced Cement Concrete (RCC) slabs were used in the up-flow roughing filter of the AIRUs to retain the media. Again perforated PC Ferro-Cement (FC) slabs were used within the down-flow flocculator. The construction of RCC and PC-FC slabs were found difficult in the rural environment and, therefore, these slabs were replaced by commercially available economical plastic plates.

Step-wise modifications made in response to the performance of the installations at the field and opinion of the users led to a user-friendly system.

CONCLUSIONS

The main findings from this study have been summarized below:

- Arsenic and iron removal efficiencies of over 75 and 85%, respectively, were achieved through the developed AIRU unit without using any chemical,

- Appropriate modifications in the design of the developed unit reduced the propensities of water head-loss and media clogging, thereby yielding sustained flow rate,
- The clogging of the filter media of the treatment units was not frequent and the cleaning procedures were simple. Cleaning was performed without removing the filter media. After the 1st, 2nd and 3rd flushing, up to 85, 95 and 98% flow recovery, respectively, was achieved and
- Efficient sludge management was ensured through proper drainage and safe disposal facilities.

Simple construction using locally available materials, considerable treatment performance as well as ease of operation and maintenance present the developed system as a sustainable solution to the water supply problems in arsenic and iron affected areas of Bangladesh.

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