Arsenic Mitigation

Action Research Findings

WATSAN PARTNERSHIP PROJECT

SWISS AGENCY FOR DEVELOPMENT AND COOPERATION

Dhaka, Bangladesh

14 sheets

Preface + 1-13

Preface

The primary objective of the SDC-WatSan Partnership Project (WPP) is to improve the user's sustainable access and use of affordable safe water and sanitation facilities and service. However, the detection of the arsenic in groundwater has reduced the access to the safe water supply. The arsenic contamination in ground water has necessitated investigation and implementation of affordable arsenic mitigation technologies for the most severely affected people.

Presently, the WPP is pleased in having a well functioning field based water quality laboratory at Rajshahi. However, it was not in the initial project design. The WPP explored to use the existing laboratory facilities at Rajshahi level when the action researches specially the SODIS, SORAS and two bucket unit were initiated. However, the support from the existing laboratories available at Rajshahi were not as expected and there were lot of bureaucratic problems. It was felt necessities by the Project Management Unit and the Swiss Federal Institute for Environmental Science & Technology (EAWAG/SANDEC) to establish a field based laboratory at Rajshahi. The flexible design of the WPP and the quality assurance commitment of the SDC have made it possible to establish a field based laboratory on January, 2000 at Rajshahi in a partnership way. The laboratory was established with the objectives of conducting water quality testing and action researches for affordable technologies for the most severely arsenic affected people in the WPP area. The laboratory was also designed to conduct smooth monitoring of water quality parameters and to verify the test results of the kits at the fields in the arsenic screening program.

By definition, an action research is a type of research work, which aims to solve problems in a program, organization or community. Immediate action and solving problems as quickly as possible are the desired results of an action research. The WPP action researches were aimed at to address the safe water supply problem immediately in arsenic contaminated area. The action researches were confined within the different available mitigation options, not to develop or to conduct basic research related to the arsenic mitigation. The major focuses of the action researches were to judge the arsenic removal efficiencies (in case of treatment options), possibilities of bacteriological contamination, the major operation and management problems, people's reaction and acceptability of the technologies.

The WPP classified the action researches in the following categories. These are as follows:

Alternations Option: Rainwater Harvesting, Remodeled Open Dug-well, Covered Dug-well and Rope Pump Technology.

Arsenic Treatment Technology: Two Bucket Unit, Solar Oxidation and Removal of Arsenic (SORAS), Safi Filter, Pitcher Method Filter, Alcan Filter and Shapla Filter.

Bacteria Removal Technology: Solar Disinfection (SODIS) and Terracotta Filter.

Piloting: Community Managed Rural Piped Water Supply Scheme.

Based on the action research findings, it can not be said that that there will be any universal solution of the water supply in different arsenic contaminated areas. Many of the mitigation options have limitations in its efficiency, operation and maintenance. However, these provide us an opportunity to apply some of the technologies in arsenic contaminated areas in consultation with the communities for fulfilling their immediate demand of safe water with due precaution measures. We hope these action research findings also help to continue further studies on arsenic mitigation options.

Besides, the above mentioned arsenic mitigation options there are other mitigation options available in Bangladesh and research has been conducted in the country and elsewhere to develop user and environmental friendly and sustainable water supply option for the arsenic contaminated people. We believe that the technological development in the arsenic mitigation field will certainly help the millions of affected people to get away from arsenic contamination.

Acknowledgments

These action research findings are the final outcomes of dedicated efforts of a number of persons and project partners who have directly participated and contributed in action researches of the SDC-WatSan Partnership Project (WPP). The authors gratefully acknowledge the contribution of all them.

The authors are very much obliged to the Swiss Agency for Development and Cooperation for providing the opportunities in carrying out the different action researches.

The authors have the pleasure to express the special thanks to the Action Research Committee of the WPP for formulating the guidelines for the action research, review of the proposals and interim reports and necessary guidance for conducting the action researches.

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The authors greatly appreciate the support of the Water and Sanitation Program (WSP) of the World Bank, Bangladesh in piloting the Rural Piped Water Supply Scheme. The authors also appreciate the direct involvement of the NGO Forum for Drinking Water Supply and Sanitation in carrying out a well thought and designed action research of rainwater harvesting with the support from SKAT, Switzerland.

The authors acknowledge the support of the different stakeholders especially Delhi Unicef, DPHE-Danida Arsenic Project and also private sector for offering the different arsenic mitigation options to WPP.

The authors like to thanks the local partner NGOs of the WPP for their cooperation during the field testing of the technologies in the rural communities through the Village Development Committees (VDCs). Our heartfelt thanks are owing to all VDCs involved in carrying out action researches.

Finally, the authors like to express their deep sense of gratitude and admiration to the arsenic affected community people who take all the trouble and agony in providing access and supporting the action researches.

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Rainwater Harvesting

INTRODUCTION

Rainwater harvesting (RWH) is not a common practice in Bangladesh. However, in the backdrop of arsenic contamination, rainwater has been considered as a potential source of arsenic free water.

Bangladesh is a tropical country and receives heavy rainfall due to north-easterly winds during in the rainy season. The heavy rainfall only concentrated from April to October. The rainfall from November to March is not adequate to meet the demand during the periods. Therefore, rainwater has to be stored during rainy seasons for the rest of the year. Rainwater harvesting for long-term use was not considered as a potential source in past due to unavailability of suitable catchment area and inconvenience of storing water over 5 months when it is compared with the hand tubewells.

The action research was undertaken as piloting and 60 nos. of rainwater storage tanks were constructed in Shibganj and Nawabganj Sadar upazilla of Chapai Nawabgonj district and 245 nos. of rainwater storage tanks were constructed in Chargaht and Bagha upzilla of Rajshahi district. A typical rainwater storage system is shown in Fig. 1.

Fig. 1: Rainwater Storage System

COMPONENTS OF ROOFTOP RWH SYSTEM

A typical rainwater harvesting systems mainly consist of suitable roof catchment, gutter and down pipe system, flushing system, filter (optional), storage tank and device to extract water from tank

OBJECTIVES

The objectives of the action research were to: (i) study the different designs of the rainwater storage tanks, (ii) monitor the water quality during storage, and (iii) assess social acceptance of the technology.

METHODOLOGY

The different available designs were explored in the nearby countries and within the country to develop low-cost and affordable storage tanks. These designs were further improved considering the availability of the materials and people's preference.

Water samples were collected periodically according to standard sampling protocol. The samples were collected monthly on random basis. This study is based on the water quality results monitoring during 2002. Physical parameters included measurements of pH and turbidity. The biological parameters included the test of fecal coliform and total coliform in stored water.

The users' comments on rain water quality and operation and maintenance issues were reflected through personal interviews and physical observations.

RESULTS AND DISCUSSIONS

Storage Tank

A storage tank is the most expensive component of a rainwater harvesting system. The storage tanks are constructed from different materials depending on local situation. The different design and materials were tested and the Table-1 provides the summary of cost major designs.

Table 1: Costing of storage tank.

Materials	Capacity (m^3)	Total cost (Tk.*)	Per m^3 Cost (Tk.*)
Ferrocement- molded tank	3.2	6,000	1,875
Ferrocement- molded tank	2.5	4,500	1,800
Ferrocement- molded jar	2.5	4,400	1,760
Ferrocement- molded jar	1.0	2,800	2,800
R.C.C. ring tank	2.5	4,400	1,760
R.C.C. ring tank	1.0	2,700	2,700
Brick tank	2.5	5,000	2,000
Brick tank	1.0	3,000	3,000
Brick tank (underground)	2.5	5,500	2,200
Plastic tank	0.5	3,300	6,600
Earthen jar	0.5	550	1,100

Generally, the cost of the tanks decreases with the size of the tank. However, there is an optimal size beyond which the cost again increases for per unit size. The ferrocement is not a common technology in Bangladesh and it requires an extensive training before construction. The mold required for ferrocement tank also incurred cost to the tank. The plastic is convenient, but the per unit cost is highest comparing to any other materials. Cement rings are used and constructed widely in the rural Bangladesh for sanitary latrine construction. The main advantage of this type of tank is that familiarity of the construction process and low per unit cost.

The earthen jars are now getting popularity considering the initial low cost. Earlier large volume earthen jars were not readily available. However, the project's initiative on capacity building of the private potters and sales centers encouraged in producing large volume earthen jars. 145 nos. of earthen jars were installed and still in operation. Special attention is required for the structural safety of the earthen jar.

Water quality parameters

Rainwater has virtually no bacteria count. With few exceptions, the quality of rainwater prior to interception is more consistent than that of other water sources. A general characteristic of rainwater is its low content of dissolved solids. It may be judged that rainwater in its composition is not likely to exceed the guideline for drinking water qualities. However, in using rainwater for drinking water supplies, it is not so much the quality of the rainwater itself is important, but rather the quality of the water as collected from roof and drawn from the storage tank in which the water is collected and stored for later consumption.

The bacteriological contamination is frequent in the stored rainwater. In 37.20% and 27.56% cases, there were presence of total colifom and fecal colifom respectively. The Fig. 2 shows the number acceptable nos. of water sample stored against the total tests carried out for total coliform. The results indicated significant attention required during the collection and storage of water.

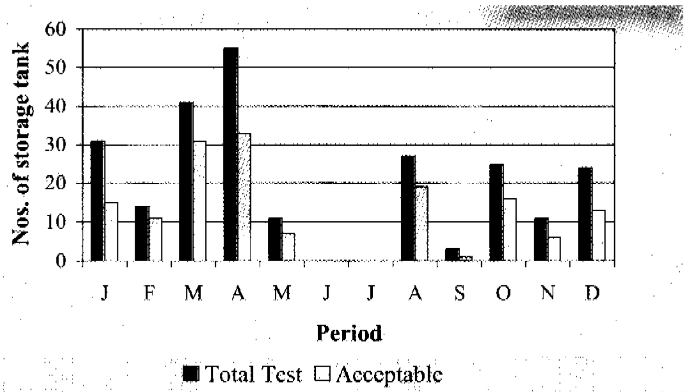

Fig. 2: Total Coliform Test (Total test and acceptable nos. Test)

Except few exceptions, the colifom number were less than 50 in 100 ml of water. A bleaching powder dose (33% chlorine) of 0.5 mg/liter to 0.9 mg/liter was found effective to decontaminate the stored water.

The pH of the fresh rainwater varied from 6.8 to 7.3 in the study area. However, the pH values of the stored water were higher than the normal pH range (6.5 - 8.5). The pH value of the standard design of storage tank with ferrocement, cement ring or brick tank were higher comparing to the earthen jar or plastic tanks. The highest pH was recorded 11.7 in ferrocement tank. The average pH value of the standard tank was 10.3. This high pH value in standard design was probably due to the properties of cement ingredients and difficulties in finishing the inner side of the tank/jar. The pH values gradually reduced with the time, but still higher than the guideline value. The pH value in plastic tank is almost constant and the average value is 7.9. The average value of pH of the earthen jar is 8.0.

The turbidity of the stored water was in the range of 5-10 NTU. This also indicated that the stored rainwater is clear, which comes first for aesthetic reason.

Social aspects

The initial response and attitude of people towards using the limited amount of stored water throughout the year was not very positive. The implementation of the program required intensive awareness activities regarding the arsenic contamination and usefulness of rainwater harvesting. Presently, 305 nos. of rainwater harvesting system are being used at the household level. The rainwater harvesting can fulfill their requirement from 7 (seven) to 10 (ten) months depending on storage tank volume, catchment area, family size and water demand. People are being habituated and practiced the dual water supply options i.e., rainwater harvesting in the rainy seasons and subsequent months and distant arsenic safe tube-well for the rest of the periods of the year. The users accepted the taste of the rainwater. As rainwater is iron free, it is better for cooking purposes.

CONCLUSIONS AND RECOMMENDATIONS

The rainwater is free from two extreme contaminants i.e., arsenic and fecal coliform (with due care). The major advantage of the rooftop rainwater harvesting system is that the system is independent and suitable for scattered settlements. The operation of the rainwater harvesting is easier than other water supply system, but special attentions are required to ensure no secondary contamination of stored water. The cost for R.C.C. storage tank (Tk. 1,760/m^3) is found relatively cheaper than other standard materials tank and the technology is also available. The earthen jars are becoming popular and poor people can afford the system and increase storage volume gradually.

Based on the findings from the action research, it has been recommended that rainwater can be adopted in WPP as an arsenic mitigation option with certain precautions.

FEATURES OF RAINWATER HARVESTING

Installation cost	Tk. 1,100 - 6,000/m^3.
Recurrent cost	[redacted]
Family coverage	Household type system. Normally combined with other technology for dry seasons.
Taste of water	[redacted]
Arsenic content	Arsenic free source.
Other parameters	High initial pH, dependent of storage materials .
Fecal coliform	Secondary contamination can leads bacteriological contamination.
Limitations	Adequate clean catchment is prerequisite. Attention required for flushing out the first rain.

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Remodeled Open Dug-well

INTRODUCTION

The action research included the study on 22 open dug-wells implemented in arsenic affected areas within WPP. Although these dug-wells had exposed openings, their appearances had been somewhat altered from their traditional looks. The objectives of such modification in design were to maintain plenty of air circulation so that arsenic concentration cannot buildup, if there is any, and to safeguard water from possible threat from bacteriological contamination. The designs were, thus, realized in such a way that results in maximising the benefits while reducing the risks and the costs.

Contrary to its name, open dug-wells have sliding covers usually made up of CI sheets (Fig. 1). These covers are placed on top of the wells when they are not in use. At the time of water collection, the sheet is moved aside or half folded depending on the design. A wide concrete platform surrounds the dug-well ring. A shade, made up of tin, is raised aloft the dug-well to protect droppings of birds, dry leaves and/or deliberate throwing of nuisances into the dug-well. Users draw water from the well by a bucket fixed to the beam placed across the dug-well shade to avoid secondary contamination from use of too many buckets.

The overall key challenge of this action research was to ensure continuous monitoring of the quality of water and to develop a suitable mechanism for smooth operation and maintenance at grassroots level. For operation and maintenance of the dug-wells, management committees, one for each, were formed in the neighborhood.

Fig. 1: Remodeled Open Dug-well

OBJECTIVES

The general objectives of the action research were to study the water quality and acceptability and related operation and maintenance issues of the option.

METHODOLOGY

5 out of 22 open dug-wells were selected for close monitoring during the period of this action research. The findings from these wells were then compiled at the end of the study. Sliding sheets, usually made up of CI sheet or wood, were placed on top of the openings of the selected wells to keep them covered when they were not in use.

Routine water quality parameters were tested periodically in the laboratory. The primary interest was to study the level of indicator bacteria in the water so as to apprehend the level of contamination. Other parameters included occasional measurements of arsenic, pH and iron, although these tests were limited in extent.

ACTIVITIES

The action research adopted systematic steps from planning to implementation. Some of the major activities in the series included mobilization of community people, formation of dug-well management committees, organization of hygiene behavior change (HBC) sessions, periodic testing of water qualities, finding out user's attitudes towards the mitigation option and finally preparation of a final report at the end of the action research.

RESULTS AND DISCUSSIONS

Arsenic

None of the dug-wells tested had arsenic concentration higher than the Bangladesh Standard limit. However, it was of interest to notice that arsenic slightly built up over a one-year period of time (Fig. 2). Although there had been minor increments, the causes of rise are yet to be accounted for.

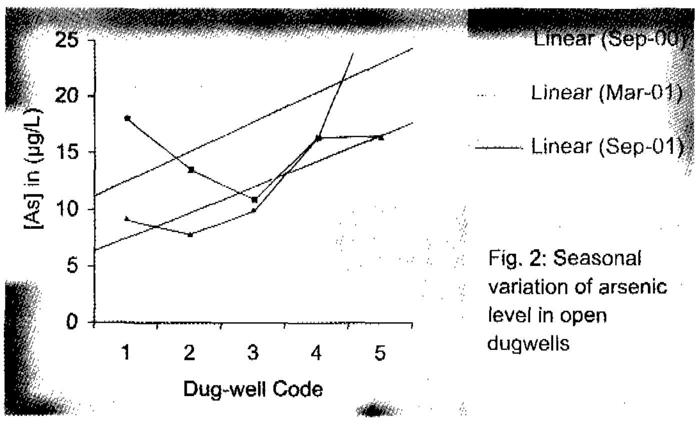

Fig. 2: Seasonal variation of arsenic level in open dugwells

Variation of arsenic contamination was significantly found in one dug-well, although it was within the permissible limit. The reason for this rise in arsenic concentration is not clearly understood. One possible explanation may be that the deepening of the dug-well depth 10 feet more (before testing second time) from its original depth might have accounted for the slight increase of arsenic level.

Bacteria

Since commissioning, three series of equivalent time interval of bacteriological tests were carried out. From test results, it was found that these dug-wells have high level of bacterial (fecal coliform) contamination. The routes of contamination are yet to be singled out, however, it is, perhaps, fair to say that contamination might have evolved because of users poor maintenance activities. Even though no immediate cases of intestinal diseases like dysentery, diarrhea and typhoid were reported, it was important at that time to ensure bacteria free drinking water for the villagers. In order to achieve the desired

Table 1: Test of bacteriological contamination using two methods.

Code	Bacteria CFU/100 ml			
	Method-1		Method-2	
	Before application	After 65 days	Before application	After 18 days
ODW-01	114	10	>200	30
ODW-06	50	50	>200	21
ODW-14	46	4	>200	50
ODW-15	150	2	>200	64
ODW-20	190	4	>200	>200

quality, dug-well water was disinfected by using two techniques described elsewhere. Commercially available bleaching powder (usually 35% of chlorine/w) is the key component used for disinfection. After treatment with bleaching doses, water from dug-wells was tested and found that the water becomes free of bacterial contamination just immediate after dosing. However, after several days later, the contamination is seen again.

Table 1 shows the test results found using two bleaching techniques. It is of interest to see that method-1 seems better performing than method-2. If we closely compare the results, we can conclude that dug-well water can remain reasonably bacterial contamination free for up to 65 days after disinfection, if the first technique is to be adopted.

There are some reported disadvantages of treating dug-well water with bleaching powder. The first of such problems is the chlorine odor of water that persists for at least 7 days after disinfection. Secondly, excessive chlorine in water may also be harmful for human health in the long run.

CONCLUSIONS AND RECOMMENDATIONS

The open dug-well has received mixed analytical appreciation both from the laboratory point of view and from the community. It was found that without treatment, dug-well water could not be kept free of pathogens for all year round. Periodic treatments with low cost oxidant such as bleaching power is required to achieve certain level of water quality.

Based on the findings from the action research, it has been recommended that open dug-wells can be adopted in WPP as an emergency arsenic mitigation option with certain precautions.

It is also recommended that dug-well should be disinfected with bleaching powder after every one month and the water quality should be checked before bleaching treatment.

FEATURES OF OPEN DUG-WELLS

Renovation cost	Tk. 3,000 - 5,000 per dug-well.
Excavation cost	Tk. 17,000 - 19,000 per dug-well.
Family coverage	On average, one dug-well serves 8 - 12 families in the community.
Taste of water	After chlorination, water may get foul smell for a week or so. Otherwise water is usually free of foul odor.
Arsenic content	During the action research period none of the dug-wells had arsenic concentration above the Bangladeshi Standard limit of 50 µg of Arsenic in L.
Other parameters	pH range of the water is 7 - 7.8.
Fecal Coliform	On average, disinfect the dug-well water using preferably bleaching technique 1 and test fecal coliforms in approx. every 1.5 - 2 months.

BLEACHING TECHNIQUES

Dug-wells were disinfected by commercially available bleaching powder (35% of chlorine/w) Lion Brand, India. The powder was bought from the local market in Rajshahi. Methods were developed following calculation of required amount of chlorine to disinfect certain volume of water in a dug-well.

Method 1

Step 1
1/2 Kg bleaching powder solution was poured onto water and homogenized.

Step 2
1/2 kg bleaching powder was kept in 2 ft from the surface water according to double-pot-chlorination method. Pot was kept 5 days in water for proper diffusion of bleaching in water.

Method 2

Step 1
100 gm bleaching powder was dissolved in 15L bucket to make clear solution with the help of stirring stick.

Step 2
Clear solution of bleaching powder was thrown into the dug-well water and homogenized by long bamboo branch. The water is then kept unstirred for 24 hours.

Step 3
After 24 hours bleached water was withdrawn from the dug-well. Newly abstracted water was used for drinking.

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Covered Dug-well

03

INTRODUCTION

The dug-well, an indigenous source of drinking water, was condemned to disuse for causing water borne diseases like diarrhea, when installation of hand tube-wells started off at a large scale during the 1970s in many parts of Bangladesh. As a result, most of the dug-wells were then abandoned. Ironically, after thirty years or so, due to appearance of arsenic, a deadly poison, in shallow hand-pump water, dug-well water, surprisingly reported by many investigators to be safe from arsenic threshold, gives a glimpse of hope for many affected people. As important it to be safe from arsenic, the dug-well also requires safeguard against possible bacteriological contamination. So, new designs or modification to the old ones become necessary to ensure safe drinking water for the users.

The covered dug-well (Fig. 1) was such a new idea that has been adapted in WPP areas, where arsenic has appeared as a threat to the health of many people. Usually, the opening of a dug-well is confined by a concrete slab with a ventilation system and the water is drawn by a tube-well: mounted either on top of the cover slab or next to the dug-well.

The action research was undertaken as piloting of a traditional option in a new innovative form. Initially, 40 covered dug-wells were implemented in both Rajshahi and Chapai Nawabgonj districts. In most cases, existing dug-wells were renovated, and only 8 were excavated.

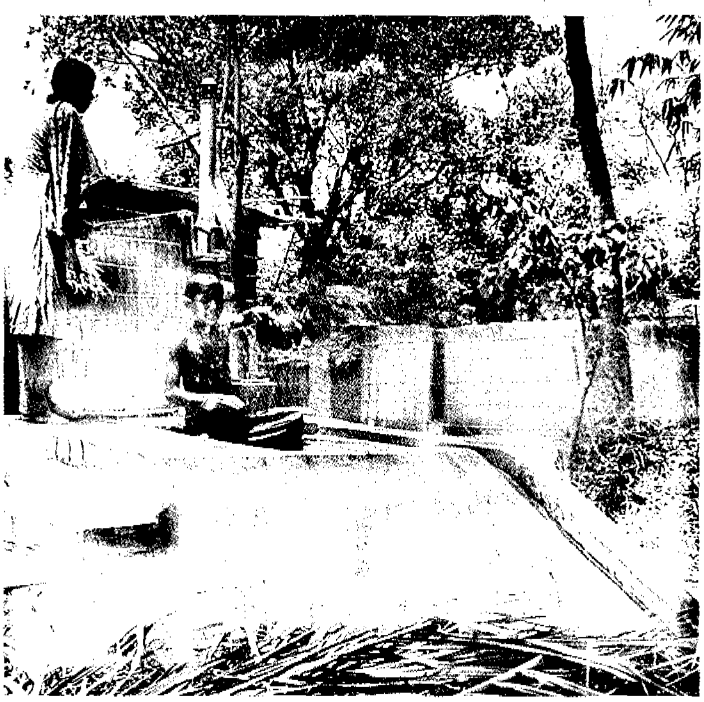

Fig. 1: Dug-well fitted with a tube-well on the cover

The operation and maintenance of dug-wells are on the hands of dug-well management committee in each village. The action research was, however, only concerned with the water quality and the issues related to proper management of dug-wells.

OBJECTIVES

The objectives of the action research were to: (i) study the feasibility of re-introducing the dug-well as an alternative water source, and (ii) identify major strengths and weaknesses of the system during the piloting phase and hence to recommend ways of improvement and/or to identify difficulties of implementing such drinking water option in the rural community.

METHODOLOGY

Water samples were collected periodically; once in a month from each dug-well, according to standard sampling protocol. Physical and chemical parameters included measurements of pH, turbidity, total arsenic (As) and total iron (Fe). Biological parameter included the test of fecal coliform in dug-well water. Samples were mainly tested periodically; however, tests were also carried out after chlorination, whenever required.

The users' comments on dug-well water quality and operation and maintenance issues were reflected through personal interviews and physical observations.

RESULTS AND DISCUSSIONS

Chemical and physical parameters

It was hypothesized that the dug-well water will be safe from arsenic and covering will protect the water from possible bacteriological contamination. 97% of renovated and 88% of excavated covered dug-wells showed arsenic concentration below Bangladesh threshold limit of 50 μg/L. However, only 56% of renovated and 38% of excavated dug-wells met the WHO guideline value of 10 μg/L.

Only 2 dug-wells contained arsenic above the Bangladeshi limit. It was difficult to account for such discrepancy; however, it may be said that this is due to the local geological characteristics. The maximum arsenic level was found to be 210 μg/L, whereas the minimum was 2.8 μg/L.

Table 1: Distribution of Arsenic in dug-well water

Type	Concentration of Arsenic in μg/L			
	0-10	11-50	51-100	>100
Renovated	18	12	01	00
Excavated	03	04	00	01
Total	21	16	01	01

From Table 1, it can be inferred that categorizing dug-wells does not necessarily provide a comprehensive picture of dug-well water quality. However, it may be fair to say that there is a probability of only 0.05 of finding a contaminated dug-well in arsenic affected areas.

There is seasonal variation in arsenic content of covered dug-wells. Although the variation is not alarming, there are a few dug-wells that showed substantial variations. During the action research period, a total of 4 dug-wells showed dramatic changes in arsenic content resulting in crossing the allowable limit. Fig. 2 shows variation of arsenic content in the selected two cases. It is of interest to see how the behavior of arsenic changed over a period of 4 months that basically encompasses two seasons: summer and rainy. Initially both dug-wells had arsenic level higher than the allowable limit, but after four months concentration in one dug-well shot up, whereas in the other, the concentration went below the allowable limit. It is hard to explain the behavior with such limited information, but it may be reasonable to apprehend that there is seasonality in arsenic level in covered dug-wells.

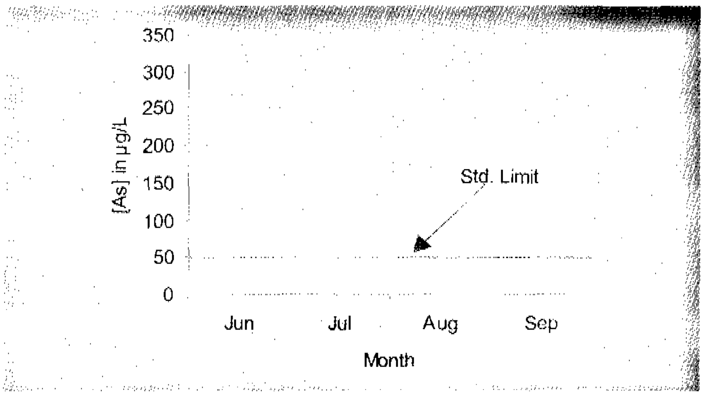

Fig. 2: Seasonal variation of arsenic in 2 dug-wells

Apart from our interest of major contaminant, arsenic, other nuisance elements such as iron was also measured. Iron (Fe) was found in the range of 0.3-8.1 mg/L with an average of 1.78 mg/L. The content was unusually high for dug-well water. However, this needs cautious interpretation.

The pH of the water was in the acceptable range of 7.0-7.8. This suggests a neutral range; in other words, water met the drinking water quality standards. The clarity of the water fell in the range of 5-10 NTU. This also indicated that the dug-well water is clear, which comes first for aesthetic reasons, enough for drinking purpose.

Bacteriological parameters

As important to be free from chemical contamination, water should also be safe from microbiological contamination. It was critical to make sure that dug-well was not contaminated by biological agents. Sealing the routes of transports of these agents into the dug-wells was achieved by covering traditional open dug-wells. Thus, the sources such as drain out from nearby areas, contamination by contacts, and deliberate throwing was prevented in covered dug-wells to some extent. However, the achievement was not remarkable as the results suggested (Fig. 3). It was found that 54.8% of renovated and 50.0% of excavated covered dug-wells met the WHO and Bangladesh standard of fecal coliform, i.e. the fecal coliform in water is 'zero'.

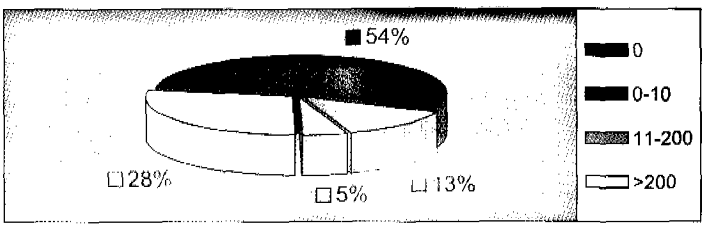

Fig. 3: Level of bacteriological contamination in dug-wells
(results in CFU per 100 mL)

It should be mentioned that most of the renovated dug-wells have been used as dumping sites for household garbage in most of the communities just before renovation. As a result, initially almost all of the dug-wells were unusable. However, after cleaning and chlorination the biological water quality improved. The techniques of chlorination have been discussed elsewhere i.e. the main report.

Social aspects

At least 306 families are currently collecting water from 39 covered dug-wells in both Rajshahi and Chapai Nawabgonj districts. On an average, 8 families depend on a single dug-well with an exception of 35 families using water from one dug-well in Shibgonj, Chapai Nawabgonj, one of the worst arsenic affected areas in WPP.

Users of 24 dug-wells said that the water quality was good in terms of taste and appearance. To the contrary, users from 4 dug-wells said that the water was loaded with iron while users of another 6 dug-wells informed that water had both iron and foul smells. In comparison, users from 5 dug-wells complained only about the odor problem. However, approximately two-third of the users were satisfied with the quality of the water.

CONCLUSIONS AND RECOMMENDATIONS

Based on the findings from the study, it is fair to say that covered dug-wells are safe enough from arsenic contamination and the water can be made free of biological contamination. The causes of biological contamination need to be carefully analyzed, as visible routes of direct injection of contaminants are apparently absent in case of covered dug-wells. However, it was believed that in most cases, contamination was accounted for past action of the users i.e. waste dumping and presently seepage of contaminants through joints of dug-wells

It was recommended that covered dug-well can be adopted in WPP areas as an immediate solution for people suffering from shortage of safe drinking water in arsenic affected areas. However, adequate measures should be taken in site selection and in operation & maintenance.

FEATURES OF COVERED DUG-WELL

Renovation cost	Tk. 7,000 - 10,000 per dug-well.
Excavation cost	Tk. 17,000 - 19,000 per dug-well.
Family coverage	On an average, one dug-well serves 6 -12 families in the community.
Taste of water	After chlorination, water may get foul smell for a week or so. Otherwise water is free of foul odor.
Arsenic content	Occasionally high arsenic content may be found.
Other parameters	pH range of the water is 7.0 - 7.8.
Fecal coliform	On average, disinfect the dug-well water using preferably bleaching technique 1 and test fecal coliforms in approx. every 1.5 - 2 months.

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Rope Pump Technology

INTRODUCTION

The rope pump technology was first introduced in Nicaragua in 1983. Later, this pump stimulated widespread interest throughout Central America due to its low cost, efficiency, durability and low maintenance needs. SDC as a pioneering donor agency as well as the promoter of the technology, is now trying to implement the same technology in countries where alternative sources of drinking water are highly demanded.

The pump is based on a centuries old design that was refined during 1980s and 1990s. It is suitable for use either at a community or family level. The basic concepts remain behind the introducing the technology are to: create a felt need by the beneficiaries, improve health conditions, make the community self-sufficient with water, introduce village level operation and maintenance, promote local manufacturer, transfer technology etc. The major achievement of the pump is that it does not require a high level technology, and this can be promoted at any level in the community.

Fig. 1: Rope pump mounted on the covered dug-well

The action research was undertaken in Paba, Mohanpur, Bagha and Chapai Nawabganj (Sadar) pazillas where most of the tube-wells are highly arsenic contaminated. The pumps were installed on the dug-wells that had been already used as alternative source of drinking water.

OBJECTIVES

The objectives of the action research were to: adopt a sanitary, socially acceptable technology that would fit with dug-wells at a more affordable price, while yielding an adequate water discharge, and providing a simpler, easier and less labor-intensive technology for drawing water particularly for women and children.

TIME FRAME AND STUDY AREA

A total of 13 rope pumps were installed in different areas under WPP during September 2001 to February 2002. Among them, 3 were installed in Paba, 4 in Bagha, 1 in Mohanpur and 5 in Nawabgonj (Sadar) upazillas.

METHODOLOGY

Selection criteria

Priorities for installing rope pump were given in areas where arsenic has appeared as a potential threat to human health. Other considerations such as water scarcity, existence of Village Development Committees (VDC), user demand, existence of useable dug-wells in the community, suitability of site selection, environmental sanitation of dug-well sites, availability of water throughout the year, and non-existence of green tube-wells around the proposed dug-wells were also taken into account during the action research.

Activities

A series of interlinked activities were performed during the action research period. Some of the important tasks included: orientation for staffs at WPP, PNGO staff training, Mason (mistry) training, users' orientation on operation and maintenance, collection of shared cost for the technology, arsenic tests and monitoring of dug well water by E-Merck kit, laboratory tests for bacteriological and other chemical tests, disinfection, and interview and FGD with users twice a month.

The survey carried out included basic demographic information of all families, information regarding quantity of water consumed per day, operation and maintenance systems etc. with individual interview and Focused Group Discussion (FGD) session.

Test of water quality parameters

For the measurement of arsenic, E-Merck field test kit was used on the spot. The concentrations of arsenic are measured semi-quantitatively. Most importantly, the dug-wells were monitored for fecal coliform in WPP Laboratory, and periodically treated with simple bleaching powder during the action research period. In general practice, 200 g of bleaching powder is primarily used to control bacteria in dug-wells. The process is cost effective and easy to operate.

RESULTS AND DISCUSSIONS

Arsenic

It is fairly accepted that dug-well waters are free from arsenic contamination. However, for taking a cautious path to establish a new technology, arsenic was tested periodically; at least once in a month using a semi-quantitative E-Merck field test kit. There was no evidence of presence of arsenic in excess of the Bangladesh Standard limit of 50 μg/L in drinking water. Even, no seasonal variation was seen during the seven-month monitoring period.

Bacteriological test

The major concern for dug-well water is the chances of biological contamination. So, it is equally important for dug-well water to be free from bacterial contamination, and the major task of investigation was to monitor the biological water quality. These tests were conducted in WPP laboratory by membrane filter technique. Each dug-well was disinfected twice during the action research period; before installation of rope pumps and two weeks after installation.

The experience found with dug-well water in this case was no way different from other studies i.e. covered and open dug-well action research. It was also seen here that the level of contamination goes up after a few weeks of disinfection. Table 1 shows the variation in the levels of coliform bacteria found in each dug-well fitted with rope pumps.

Table 1: Fecal contamination in DW water

[illegible]	Oct 01	Jan 02	Feb 02	[illegible]
		CFU per 100 mL of water		
1	28	12	6	8
2	112	04	22	nil
3	92	nil	8	10
4	>200	20	60	20
5	>200	>200	6	[illegible]
6	150	-	4	nil
7	>200	56	50	14
8	>200	>200	12	>200
9		90	120	>200
10		176	8	nil
11		8	4	12
12	-	120	>200	>200
		-	54	nil

Just looking at the above table, it can be inferred that it was hardly possible to ensure bacteria free water through the rope pump. Only five times (approx. 11%) of the total measurement episodes, no indicator bacteria were present. Perhaps, this is an inherent problem with dug-well water, as it was the case for other studies. Rope pump hardly has any influence on the growth of bacteria; rather, it may reduce the chances of multiple contaminations, if the water to be drawn by other modes.

Discharge through the pump

With a minimum effort, the pump discharges a large quantity of water that makes the pump user friendly. For a minute of operation, the pump discharges as much as 23 to 32 liter of water in a one go. It is usually higher than any other suction pumps functioning with dug-wells.

Users' comments

During the monitoring study, it was found that users like the technology quite much. They think the operation and maintenance are simple and easy, and the manufacturing and repair works of the pump can possible be done by the local constructors.

The cost of the pump will be affordable, only if it is constructed in the community. The most spectacular thing about the technology is that it protects possible contamination of water by foreign elements as the study revealed. The general people are happy about it, as they get safe water from dug-wells, at least they don't have to drink contaminated tube-well water.

Advantages

The prominent advantages of the technology are listed as follows:

- Keeps water quality better compared to open dug-well water.
- Easy operation and maintenance.
- Can be manufactured locally with available technologies.
- Maintenance cost is low.
- Discharge is high compared to other hand-pumps.

Limitations

Although there are some advantages of the technology, some disadvantages also prevail:

- More costly than simple rope and bucket method.
- Special type of washers or knotted ropes required.
- Technically complicated than simple rope and bucket method.

CONCLUSIONS AND RECOMMENDATIONS

Rope pump is a technically simple and easy water-lifting device. It can be manufactured with local available materials and skills. It prevents foreign elements entering into dug wells in most cases. People also appreciated it much as it is a user friendly technique for water abstraction. So, there is a social acceptance in the community, specially, in areas where arsenic has appeared as a threat for human health. In the end, it is recommended that rope pump can be adopted in arsenic prone areas with due consideration. Even, the opportunity for installation should also be explored in non-arsenic affected areas. Special attention should be taken regarding disinfection.

FEATURES OF ROPE PUMP

Installation cost	Tk. 1,200 (only pump cost).
Family coverage	On an average, one pump serves 8 - 12 families in the community.
Taste of water	After chlorination, water may get foul smell for a week or so. Otherwise water is free of foul odor.
Arsenic content	Usually low arsenic content in dug-well waters.
Fecal coliform	On average, disinfect the dug-well water using preferably bleaching technique 1 and test fecal coliforms in approx. every 1.5 - 2 months.
Advantages	User friendly, easy O&M, low management needs etc.

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Two Bucket Unit (TBU)

INTRODUCTION

Two Bucket Unit (TBU) is a household based arsenic removal unit that works on the principle of coagulation-adsorption and co-precipitation process. It consists of two buckets, each of 24 L of capacity, placed one on the other. Contaminated water is placed in the top bucket, usually red. 1 spoon of the supplied reagent (usually a mixture of alum: potash=100:1) is then mixed thoroughly with a wooden stirrer for at least 1 to 2 minutes. The mixed water is put at rest for 2 hours on the red bucket. When the coagulants are settled nearly at the bottom, the water from the top bucket is then released through a connecting pipe to the bucket at the bottom. The water at the green bucket is finally filtered through a sand based column filter kept within the bucket. Filtered water then can be consumed directly. DPHE-Danida Arsenic Mitigation Pilot Project first introduced this treatment technology. Fig. 1 shows the bucket arrangements of two-bucket unit (TBU) system

Fig. 1: Bucket arrangement of two-bucket unit

The action research on two-bucket unit was subjected to rigorous testing at WPP laboratory before it was introduced at field level. During the action research period, a total of 19 bucket sets were installed in arsenic affected families of Rajshahi and Chapai Nawabganj districts. The action research was carried out for two years: 1999-2000.

OBJECTIVES

The major objective of the action research was to investigate arsenic removal efficiency at field level. Other objectives were to: study socio-economic acceptance and identify the 'problems and prospects' associated with the system, and finally, to make recommendations on the basis of observations and results.

METHODOLOGY

A number of physical and chemical water quality parameters including pH, iron (Fe) and arsenic (As) were measured at the laboratory following the standard sampling and analysis protocols.

To study the social acceptance, a systematic questionnaire survey was conducted. The major areas of intervention were economic and gender considerations, mechanical convenience and social acceptability.

RESULTS AND DISCUSSIONS

Arsenic removal

The average arsenic removal of 19 sets was found to be approximately 85% with different groundwater conditions in Rajshahi and Chapai Nawabganj districts. As a result, this system is limited to use for water containing arsenic level below 330 µg/L only so as to bring the final concentration of arsenic in the treated water below the Bangladeshi standard level of 50 µg/L. Fig. 2 shows the correlation between arsenic concentration in raw water and the removal efficiency for corresponding value.

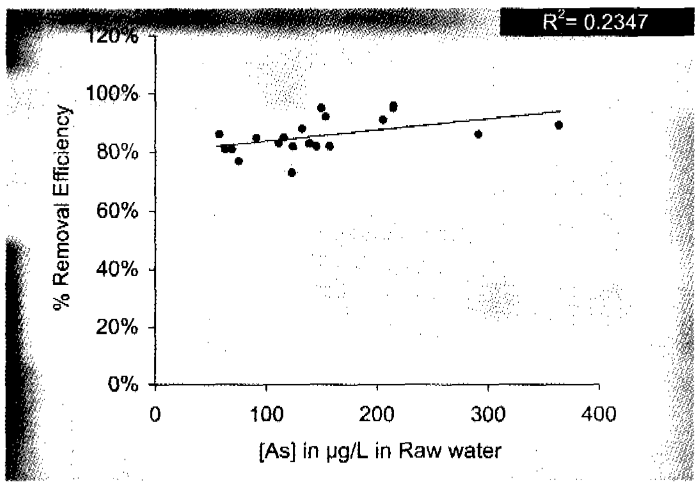

Fig. 2: Correlation between removal efficiency and arsenic concentrations in raw water

Just looking at the R^2 value in the above graph, it can be inferred that there is hardly any correlation between the two variables. However, it indicates an important aspect about the operational efficiencies of the users at field level that is, if much uniform level of performances from the users side could have been attained, the correlation between the variables could have been much stronger.

The results from the 19 sets can be interpreted in other ways such as 21% (4/19) of the sets had arsenic level below 10 μg/L (WHO guideline value) and 79% (15/19) had below Bangladeshi standard in the treated water.

It was found that arsenic removal efficiency of the units could have been improved by increasing stirring and settling time slightly.

An attempt was also made to improve the efficiency of the present system through introducing a new dosing method using the similar chemicals, but in different proportions in the mixture. It was found that increasing the ratio of permanganate in the mixture and using 1.5 spoons instead of 1 spoon can also improve the removal efficiency upto 92%. However, the filtered water suffered from slight coloring from use of excessive permanganate.

Iron removal

The filter also removes iron substantially. It is observed that the system can remove upto 92% of total iron from raw waters.

Water discharge

The average discharge rate of this system was reported to be 20 L/3 hrs, while considering 2 to 3 hrs of settling time for the flocs to settle. This may be considered a high output, since a family may use this system for as many as three times during a day for their water consumption for drinking and cooking.

Social aspects

It was observed that a total of 106 people of 24 families were using these systems introduced in Rajshahi (52%) and Chapai Nawabganj (48%) districts. It was reported that approx. 74% users used this method throughout the year, while 16% stopped using only in summer (mainly due to high water temperature in bucket) and 10% for both summer and winter seasons (Fig. 3 shows the use pattern of two bucket treated water).

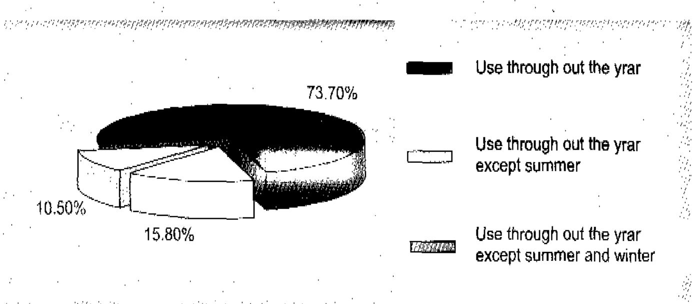

Fig. 3: Use pattern of two-bucket unit treated water

It was found that 68% of the total sets gave good services throughout the year as the users handled these carefully. On the other hand, remaining 32% had several technical problems due to lack of proper handling. 53% users think that the operation and maintenance of the system is easy, and the rest thinks it is difficult.

Advantages

This technology is able to provide water for required quantity and quality providing the limitations of the system. The treated water of this system is very light, colorless and odorless. The reagents and accessories are cheap and locally available. In this system, the chemicals used are safe in handling and can be stored safely without causing any undue health risk. This method allows no secondary bacterial contamination for the presence of disinfectant materials in the filter media.

Disadvantages

The plastic buckets may crack, if not properly handled and leakage problems in the joints of taps may appear as a severe drawback for the unit. The treated water becomes hotter during summer and colder during winter in compare to tube-well water. The sludge can have secondary environmental health hazards, which needs adequate research.

CONCLUSIONS AND RECOMMENDATIONS

Two Bucket Unit (TBU) is capable of treating arsenic laden water providing the limitations of the system. It can remove arsenic up to desired level, and also can provide bacteria and iron free water. However, the action research did not test the residual aluminum content in the water.

Although this method has some limitations like leakage and sludge management problem, it is acceptable to most of the users in the community. Users are fully satisfied with this treated water. Therefore, Two Bucket unit can serve as a simple and affordable arsenic mitigation option for a short-term basis in WPP areas.

FEATURES OF TWO-BUCKET UNIT

Removing metal ions	Mainly As and Fe.
Avg. removal efficiencies	As (85%) and [redacted]
Discharge rates	20 liter per 3 hours.
Taste of treated water	Odor free and has good taste.
Availability	Can be manufactured locally.
Installation and reagent costs	Tk. 350 - 400/-, Tk. [redacted]
Material recharge time	Depends on arsenic level in raw water and use pattern.
Advantages	[redacted] maintenance, enough water supply etc.
Limitations	Leakage through the joint, produces sludge etc.

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Solar Oxidation and Removal of Arsenic (SORAS)

06

INTRODUCTION

The action research on SORAS (Solar Oxidation and Removal of Arsenic) was conducted in collaboration with SANDEC-EAWAG, Switzerland. It is an arsenic removal method that uses sunlight and few drops of lemon juice to treat iron laden arsenic containing water in a 1.5L PET or other UV-A transparent bottles. Because of absence of a suitable technology for arsenic removal from drinking water, SORAS was conceived as a temporary solution on emergency basis for those who have been drinking arsenic contaminated water in WPP areas.

The key challenge here was to make SORAS a household based low-cost arsenic removal technology. After series of experimental work both in laboratory and field conditions, few families were given the treatment option and observations were recorded thereafter. Fig. 1 shows the SORAS set-up at field level.

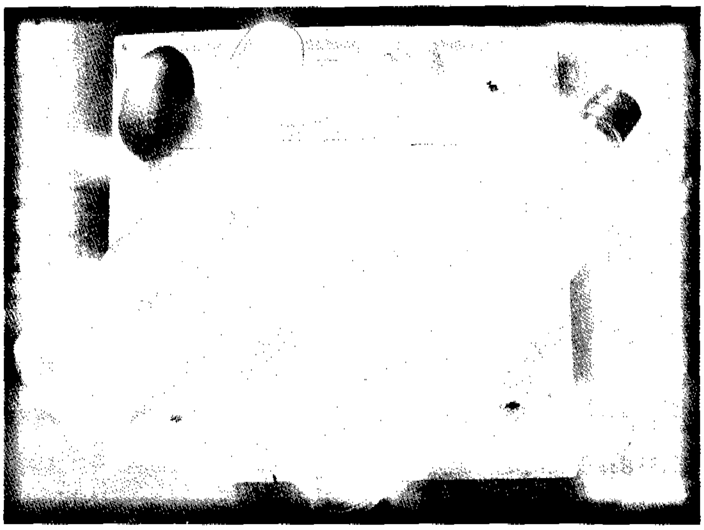

Fig. 1: SORAS Setup

THE PROCESS

SORAS removes arsenic in a two-step procedure. In the first step, arsenic (III), which only weakly absorbs to iron hydroxides, is oxidized in the presence of sunlight to strongly absorbing arsenic (V). In the second step, arsenic (V) is absorbed onto iron (III) hydroxide particles formed from naturally occurring iron. The procedural steps involved in SORAS practice are given below:

- Fill 4/5 of the plastic bottle (approx. 1.5 L) with freshly pumped groundwater.
- Add approx. 6 drops of fresh lemon juice per liter of water.
- Shake the bottle vigorously for approx. 30 seconds.
- Expose the plastic bottle in horizontal position to sunlight for a full day.
- Turn the bottle in vertical position and leave the solids settle over night.
- Decant the supernatant water carefully the next morning or filter it trough a piece of clean cloth.

OBJECTIVES

The objectives of the action research were to enhance arsenic removal efficiency of SORAS using locally available materials and to test the feasibility of implementation of this method in WPP.

EXPERIMENT

At the laboratory in SANDEC, Switzerland, simulated water having similar features of contaminated water in WPP areas was used to develop SORAS. During the field campaign, however, groundwater from contaminated tube-wells was used for method improvement. In order to enhance the efficiency of the method, a series of citric juices as well as some other chemicals such as potash (potassium permanganate-oxidant) and iron salts were used as additives. Nevertheless, to keep the cost of the method low, the use of lemon juice, which is locally available, was researched more than any other juices. Addition of permanganate improved the efficiency; but the idea of adding synthetic chemicals was not facilitated in the long run.

Measurements of arsenic were carried out by an Arsenator 510 at WPP Laboratory and by more sophisticated techniques i.e. Perkin Elmer 5000 Atomic Absorption Spectroscopy (AAS) equipped with a batch MHS-20 Mercury/Hydride generator in SANDEC. Other chemical parameters (e.g. Fe, Mn, pH, O_2, COD, hardness, alkalinity, nitrate, phosphate) were measured with field kits and in the laboratory.

SORAS FIELD TEST

3 series of field tests were carried out. The first phase experiments included tests with 7 tube-wells during the end of the dry season (April June '99), the second with 5 at the end of the wet season (October-December '99) and the third one with 2 tube-wells in the dry period (March'00). In all experiments 1.5-liter PET bottles were used and arsenic concentrations analyzed by Arsenator 510 and partly crossed-check in the laboratory (i.e. AAS).

RESULTS

Laboratory test results showed that with typical groundwater conditions, addition of citrate increased arsenic removal up to 80-90%. A limited number of experiments were conducted with water containing silicate and phosphate. With 2 mg/L phosphate and 50 mg/L H_4SiO_4 (typical in some tube-wells) the removal efficiency was somewhat lower, but still between 80-85%.

Furthermore, the field tests carried out during different climatic periods and fluctuating groundwater tables revealed that the arsenic concentration varies with time. The respective level at the end of the wet season can, in some cases, be nearly twice as high than at the end of the dry season. Most of the arsenic found in the groundwater is in its reduced form i.e. As (III).

The arsenic removal efficiency depends to a great part on the iron concentration, which should not be smaller than 3 mg/L and on the dissolved oxygen concentration. The low oxygen content of the pumped water generally varies between 1-2 mg/L. Due to the oxidation of the dissolved iron the color of the initially clear water changes to reddish brown within a period of 30-120 minutes. Shaking of the partly (approx. 4/5) filled bottles with groundwater for about 30 sec increases the dissolved oxygen concentration to 6-7 mg/L. The almost oxygen-saturated water accelerates the oxidation of the dissolved iron and is, therefore important to increase the efficiency of the SORAS process. The arsenic removal efficiency depends on the relation of the iron and arsenic concentration and varied between 56 and 88% for the raw water of the tested tube-wells.

As studied by laboratory tests, photochemical oxidation of As (III) and Fe (II) is accelerated and more complete in the presence of citrate. In the field, citrate is replaced by lemon juice. Different types of lemon such as the juicy "Kagoji" and "Kakja" are available in Bangladesh throughout the year except for a 2 months period (February March). The different experiments revealed that approx. 3-10 drops of lemon juice per liter of water should be added immediately after filling the bottle with pumped groundwater. A too high concentration of lemon juice reduces the efficiency of SORAS as it is the case when the dosage is not carried out immediately after pumping. Finally, adding more lemon juice during irradiation neither hinders nor improves the final arsenic removal efficiency.

The photooxidation process is driven by solar radiation and hence, irradiation duration and intensity are rather important parameters. The experiments proved the longer the irradiation and higher the UV-A radiation intensity the more efficient is the SORAS process. Best results were obtained by irradiating the water throughout the day under clear sky.

The experiments revealed that the greater the iron content in the water, the sooner occurs the flocculation (first flocs after 90 min for 8.35 mg Fe/L as compared to 195 min for 4.65 mg Fe/L). After the irradiation phase, the plastic bottles have to be turned from horizontal into vertical position to allow an efficient separation of the flocs. Slight shaking of the bottles does not enhance the flocculation and, therefore, the bottles should rather be left still during the solid separation phase, which normally is completed after a few hours. Finally, the settled particles have to be separated from the water either through decantation or filtration through a piece of clean cloth.

The field tests revealed lower removal efficiency than what was observed in the laboratory. The reason for this might be that Bangladesh groundwater shows a large variability in water constituents. Constituents such as silicate, natural DOC (dissolved organic carbon), phosphate etc, might have a significant influence on As (III) oxidation and on subsequent removal by adsorption and precipitation. The arsenic removal efficiency of the SORAS method is between 45-78% and averages 67%. Concerning the Bangladesh guideline value of 50 μg/L arsenic in drinking water, SORAS can treat raw water containing at arsenic concentration below 100-150 μg/L provided sufficient iron and UV-A intensity is available. Addition of potassium permanganate (if necessary together with aluminum sulphate), achieves a higher arsenic removal efficiency, approx. 80% and 90%, respectively. Hence, SORAS (+) would allow treatment of raw water containing a higher arsenic concentration.

Preliminary field tests carried out with 4 families revealed that the people are primarily interested to remove the iron. Unlike arsenic, a high iron concentration in the water can be easily detectable by it's color, smell and taste. The SORAS treated water is clear and "light". The people like the taste and they say that food cooked with this treated water keeps its natural colors and freshness, e.g. cooked rice and vegetables are not anymore of a red brown color. People living in arsenic affected areas seem to be prepared to use the SORAS treatment method. However, lemons are not always available and the cleaning of bottles is somewhat cumbersome. Potassium permanganate could be used during periods of low sunlight radiation or non-availability of lemons.

CONCLUSIONS AND RECOMMENDATIONS

The arsenic removal efficiency is limited to approx. 50-70% and hence, raw water up to 100-150 μg/L can be treated with this low cost method. SORAS can be a low cost option that can be used for as a interim measure until better options might be available.

Use of SORAS at household level did not receive a spontaneous welcome, although people seemed to be aware of the effects of arsenic in drinking water. It is perhaps because of the imparting limitations of the technique that did not encourage WPP to adopt this option in the field level with large scale.

It may be noted that the technology was tested as the development stage in the WPP.

FEATURES OF SORAS

Cost	Tk. 30 - 50 per month per family of 4 members
Removal efficiency	Approx. 50 - 70% (As).
Limiting concentration	As: 150 μg/L in raw water.
Taste of water	Water also becomes free of iron. So, the water feels light and odor free.
Limitations	Does not work in cloudy days, lemon is not available throughout the year. Again, addition of chemicals is cumbersome.

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Safi Filter

INTRODUCTION

Safi Filter is one of the pioneer arsenic removal technologies developed in Bangladesh. It has been available in the market since early 1999. It is a household type candle filter, and has two sizes: standard (capacity 20-22 Liters) and small (capacity 10-12 Liters) (Fig. 1). There are two compartments in the barrel shaped filter system; the top compartment has the candle and the bottom compartment reserves the filtered water. The candle is made up of composite porous materials such as kaolinite and iron oxide on which hydrated ferric hydroxide is impregnated by sequential chemical and heat treatment.

The filter works on the principle of adsorption-filtration on chemically treated active porous composite materials of the candle. The hydroxides of Fe, Al and Mn predominantly remove arsenic, iron and bacteria without deteriorating the taste of water.

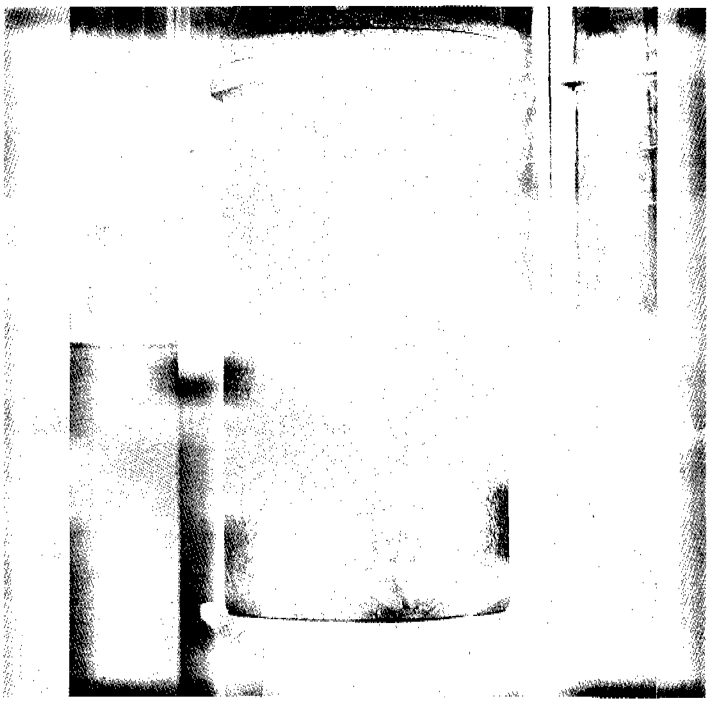

Fig. 1: SAFI Filter

WPP Laboratory acknowledged three filters from one of the marketing agencies of the filter: one from the first generation and two from the second-generation types. As part of WPP's policy on 'adoption of arsenic technologies in its areas', the filters went through a series of performance study including physical, chemical and biological parameters initially at WPP Laboratory. Based on the findings, some recommendations were made at the end of the action research.

RESEARCH STATEMENT

Can the performance of Safi Filter be justified in treating arsenic laden water in WPP area - was the research query.

OBJECTIVES

The objective of the action research was set to study the claimed performance of Safi Filter through a series of appropriate tests at the laboratory. Based on the findings, thus to recommend whether to adopt this technology in WPP area or to reject all together.

METHODOLOGY

The study was conducted for 9 weeks during the months of June'00 to Agust'00. The feed water was collected from contaminated tube-wells of the village "Utter Kazipara" under Boalia thana of Rajshahi district and from Chapai Nawabgonj Municipality area. Water was collected in plastic drums of 50-liter each, throughout the study period. The system ran on 'pour and pass' action. So, the filter never remained empty as the continuous supply of water was ensured. When raw water was added to the filter, desired parameters of both raw and treated water were measured. Sampling and analysis were conducted according to the standard procedures. Water quality parameters tested are described in the following section

RESULTS AND DISCUSSIONS

Physical and Chemical Aspects

i. The filtered water was clear and had good taste, although the water tasted a little bit 'earthy' at the beginning of use.
ii. The pH of the treated water was found to increase slightly from the level in raw water. The average pH was 8.2. Although it was within the guideline value, pH always increased in treated water from the level in raw water. However, the increment did not vary much only from 6.3% to 16.0% with an average of 10.2%.
iii. The discharge rate of the filter through the candle was 32-36 liters per day for both generation types.

Table 1: % Arsenic (As) and Iron (Fe) removal efficiencies

Filter	Avg.	Range	Avg*	Range
Filter-1 (1st Generation)	65.9	75.6-52.2	97.9	98.8-97.1
Filter-2 (2nd Generation)	71.3	81.7-55.0		
Filter-3 (2nd Generation)	68.0	73.0-63.0		

Bacteriological Tests

The filter reduced the level of bacteria in raw waters, although filtration could not eradicate all of them.

Interpretation

- The filter did not spawn any bacterial growth as it was seen that if the raw water is free from bacteria then, the treated water is also free from bacterial contamination.
- For both types of filters, the %removal efficiency was almost the same; the 2nd generation filter showed an improvement of only approximately 5% from the previous make. However, this can be explained in that the 1st generation filter showed decrease in removal efficiency after used for 13 weeks. Note that during the 1st phase, the efficiency of the filter was 71% over 4 weeks time, compared to only 66% for the next 9 weeks.
- The trend in removal efficiency over time was not clear in either of the filter types. i.e. both had varying degrees of shifts in the trend (Fig. 2).

- The distribution frequency of removal efficiency (for 2nd generation filter) showed that the %removal efficiency was highly grouped in the 76%-85% interval i.e. not a 'normal distribution'.
- The filter merely showed any relation of %removal efficiency with concentration variation of arsenic in the raw water (Fig. 3) i.e. the %removal efficiency did not either reduced or increased with increasing or reducing arsenic concentration in the raw water.

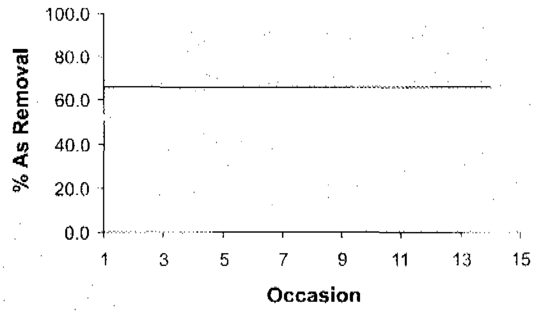

Fig. 2: Trend in removal efficiency over time

- The filter showed an effective removal (to bring down arsenic concentration below Bangladesh permissible limit in treated water) of arsenic from the raw water, if the raw water contained only 150 µg/L or less of arsenic.

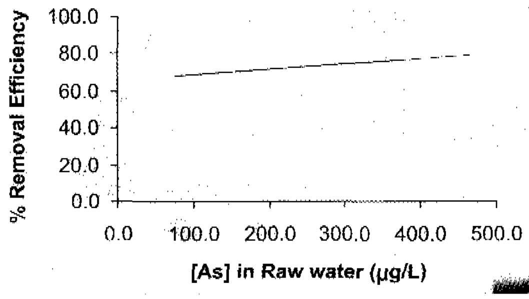

Fig. 3: Correlation between arsenic concentration in raw water and removal efficiency

Discharge rate

The daily output water through Filter 1 was 30-32 L/day, which was approximately the same for Filters 2 and 3.

ADVANTAGES

- Simple and easy operation and maintenance. Maintenance cost is not very high (only Tk. 250 for the candle after two years).
- Ideal for a small family. Also, better for women, who are the ultimate water collector, need not to go out for water collection.
- Water taste is usually retained in the treated water.
- Can be used as iron removal unit too, as iron is a recognized problem in this region.

LIMITATIONS

- The filter can serve the purpose only when the arsenic concentration of contaminated water is below 150 µg/L.
- The candle materials may leach into the treated water and thus may have extended implications on health for long time use i.e. Aluminium (Al) and Manganese (Mn) may be present in the filtered water.
- Very slow water delivery rate and candle gets clogged very quickly may be in 12-15 days.
- The candle joint may collapse due to manual cleaning/ scrubbing of the candle from time to time. Although the 2nd generation filter has a cloth net over the candle, again that needs frequent cleaning.
- Installation may appear costly to affected marginalized people.

CONCLUSIONS

Safi Filter system showed considerable removal efficiency (65-70%) for arsenic as compared to iron removal efficiency (97%). This limits its use for only well water containing arsenic below 150 µg/L. The system could produce as much as 32-36 liters of arsenic safe water in a day, which, again made its acceptability family size specific, may be only for families having 2-3 members. Dumping of used candles in the environment needs serious consideration as the impact is yet to be investigated.

As the removal efficiencies of Safi filters were not at the desired levels, it was not recommended for the field level testing.

It may be noted here that the inventor made some improvements of Safi filter. It was reported that the removal efficiencies improved significantly. However, WPP did not test improved version of Safi filters.

FEATURES OF SAFI FILTER

Removing metal ions	Arsenic (As), Iron (Fe).
Removal efficiencies	As: 65 - 67% and Fe: 97 - 98%.
Limiting concentration	As: 150 µg/L in raw water.
Taste of water	No [illegible]e change of raw water, pH 7.5 - 8.2
Filter capacity	32 - 36 L per day.
Cost	Tk. 1150 for small type.
Availability	Not available in local market, supplied from Dhaka.
Filter recharge time	[illegible]
Advantages	Easy operation and maintenance.
Limitations	Clogging of the filter candle, joint leakage etc.

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Pitcher Method Filter

INTRODUCTION

The Pitcher Method Filter (PFM), also known as "Tin Kalsi" in local language, has three earthen pitchers placed on top of each other and firmly caged in a mild-steel (MS) or in a wooden frame (Fig. 1). Iron fillings (zero valent), sands, brick chips, and charcoal (wood coke) are the major ingredients of this filter media. 2 kg of coarse sand is placed on top of 3 kg of cast iron turnings in the top most pitcher. In the middle pitcher, 2 kg of fine sand, 1 kg of charcoal, and 2 kg of brick chips are placed in beds. The third pitcher remains empty and collects filtered water that has passed through the media in the upper pitchers. Arsenic is removed by adsorption on the media, perhaps, through formation of co-precipitates, mixed precipitates, and by adsorption onto the ferric hydroxide solids.

The filter was developed by a local laboratory in collaboration with the experts from USA. The action research was carried out for a year from August 2000 to August 2001 in WPP areas.

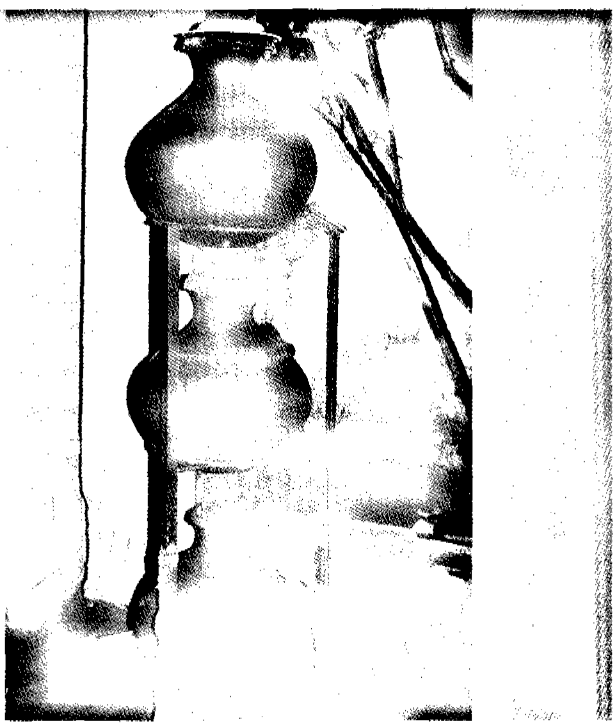

Fig. 1: 3 P[illegible] Me[illegible] Filte[illegible]

OBJECTIVES

The objectives of the action research were to investigate contaminant removal efficiencies and discharge capacity, study its acceptability at household level in the arsenic affected communities, and hence, to recommend whether or not to adopt this method as an option in WPP area.

METHODOLOGY

20 sets of the filter system were placed in 20 families in arsenic affected villages: Mintola and Khalifapara of Chapai Nawabgonj district and Uttar Kazipara of Rajshahi district. It should be mentioned that families were suggested to use treated water only for cooking and drinking purposes so that the demand and supply was assessed.

Parameters

The key parameter of interest was arsenic (As). It was measured in both raw and treated waters once in every three months at the laboratory. The treated water was tested once in a month by E-Merck field test kit on the spot. Besides, pH and iron (Fe) were also measured on a random sampling basis.

The biological parameter included study of indicator bacteria (e.g. E. Coli) of both raw and treated waters in once a month in the laboratory.

Others

The "point" at which arsenic breaks through the media was assessed based on periodic chemical testing. Daily water output through the media was measured by averaging output by minutes for few hours at different intervals during filter operation.

RESULTS AND DISCUSSIONS

Arsenic (As)

Arsenic removal efficiency was measured using laboratory technique; three sets of test episode for each filter were conducted throughout the research period. In addition to that, numerous tests were carried out using Merck field test kit one test per filter once in a month. Although the latter technique was a semi-quantitative measure, the results were useful in indicating the performance of the filter method. The summary test results of arsenic analysis are in Table-1.

Table 1: Arsenic removal efficiencies at three times

Aug-00	98.5	86.5	94.6
Feb-01	99	78	92.2
July-01	94.8	78.6	90.1

After one year of continuous use, Pitcher Method Filter still showed significantly high removal efficiency as evidenced from above table. The performance, however, decreased slightly (only about 5%) after one year of use.

The temporal variation of removal efficiency can also be presented graphically (Fig. 2). Although it is hard to see any trend in variation curves, it is fair to say that the average efficiencies decreased over time.

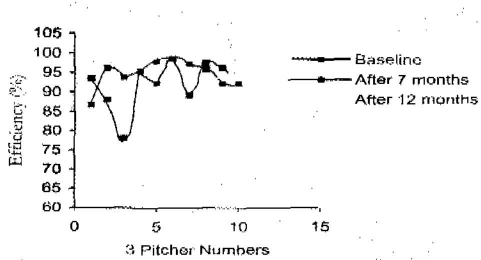

Fig. 2: Temporal variation of arsenic removal efficiency

Iron

This filter also removes iron, a major concern in WPP areas, substantially. It was found that level of iron was very high in the study areas ranging from 3.07 mg/L to 9.3 mg/L. The average iron removal efficiency was 90% (range 83.51%-96.44%, sample size was 10) studied over one year period.

Bacteria

At the beginning, the filters showed no evidence of bacteria removal capacity, although at later stage some improvements were perceived from the test results. The result showed that the level of bacteriological contamination was in the range of 0 to 25 CFU per 100 ml.

As it is important that the drinking water should be pathogen free, an experiment was also conducted to identify the source of contamination at different pitchers of the system. The results are given Table 2.

Table 2: Bacterial contamination at different pitchers (results are in CFU per 100 ml of water).

		Top	Middle	Collector
PMF# 14	4	2	Nil	24
	16	Nil	Nil	12
PMF# 15	Nil	Nil	Nil	2
	Nil	Nil	Nil	Nil
PMF# 16	8	2	Nil	30
	Nil	Nil	20	70
PMF# 17	Nil	Nil	Nil	8
	Nil	100	34	>200
PMF# 19	2	24	Nil	8
	2	10	Nil	2

From the above table, it is seen that, in case of filters PMF# 14 and PMF#19, raw water was contaminated. However, the number of coliforms decreased through filtration at first and second pitchers. In most cases (except PMF# 16 and PMF#17) bacteria was completely reduced in middle pitcher. On the other hand, the collector pitcher was too found to have bacterial contamination. It may be said that the level of bacteria can be reduced from its raw water condition through filtration; however, the treated water can still be contaminated by a secondary source predominantly by the users at the collector pitchers.

To prevent the growth of microorganisms in the filter media as well as to clarify the media, if pathogens are present, hot water washing treatment was applied to the system. When any trace of bacterial presence in the treated water was found, hot water was passed through the media to inactivate the pathogens that might be present in the filter media.

Water Discharge

The major concern of the system was the daily water output. It is a crucial aspect from a user's point of view. For the first six months, the average output was 25 to 28 liters of treated water per day through the system. To the contrary, after one year of use, the average discharge was reduced quite significantly to only 8 to 20 liters per day.

Other Findings

Initially, it was informed that the filter media could remove arsenic effectively for up to 3 months from installation. However, in the field it was observed that even after one year of use, the system reduced arsenic at high removal efficiency; as much as 90%. So it was difficult to decide on the lifetime of the media after one year of experiment.

Filter materials inside the pitchers solidified and transformed into hard chunk of solid mass, as there is no scope for washing or changing the filter materials for further use. Since the materials inside the first two pitchers solidify, it also becomes difficult to scoop out these materials and reuse the pitchers for the next time. So, two pitchers can be used for one time only.

LIMITATIONS

If iron concentration is high in raw waters, the discharge through the system is reduced earlier. But, this problem can be solved by dispersing materials inside the pitchers with a hard aluminum rod by gentle stirring in the hole of the top and middle pitchers.

Pitchers and all the filter materials cannot be used 2nd time, except the holder frame.

The environmental consequences of the discarded materials are yet to be observed.

CONCLUSIONS AND RECOMMENDATIONS

The three picture method is a treatment technology that can solve the immediate problem in a highly arsenic contaminated area.

Filter materials should be treated with boiled water or chlorinated (bleaching powder solution) water before installation.The 3rd pitcher of the filter system should be maintained hygienically, as secondary contamination may occur generally in this pitcher.

WPP may adopt this technology, since it provides very good removal efficiencies for both arsenic (major concern) and iron (secondary concern) only for short-term basis.

FEATURES OF 3 PITCHER FILTER METHOD

Removing metal ions	Arsenic (As), Iron (Fe).
Avg. removal efficiency	90% - 94%.
Avg. capacity	15 - 20 L.
Taste of water	Good.
Availability	Materials for media are not readily available in the local market.
Avg. price	Tk. 450/- per set.
Material recharge time	Max. 12 months (avg. 6 - 7 months).
Advantages	Simple and easy operation.
Limitations	Slow discharge, hardening of media, breaking of pitchers etc.

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Alcan Filter

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INTRODUCTION

Alcan is, primarily, a household based filter that removes arsenic and other undesired compounds from drinking water. The filter, developed by MAGC Company of Canada, has been imported in Bangladesh by a private company.

The filter has two compartments (Fig. 1), made up of plastic buckets, the top one, which is connected through a plastic pipe with the bottom one, contains the homogeneous filter medium and the lower bucket holds treated water. The operation is simple, only pouring contaminated water through the medium results in substantial removal of arsenic. The filter works on physico-chemical adsorption process.

The action research comprised predominantly of the study of arsenic removal efficiency and the acceptability of the filter in the arsenic affected communities. Rapid assessment at the laboratory was also an integral part of the action research. The action research was carried out for five months from May 2001 to September 2001.

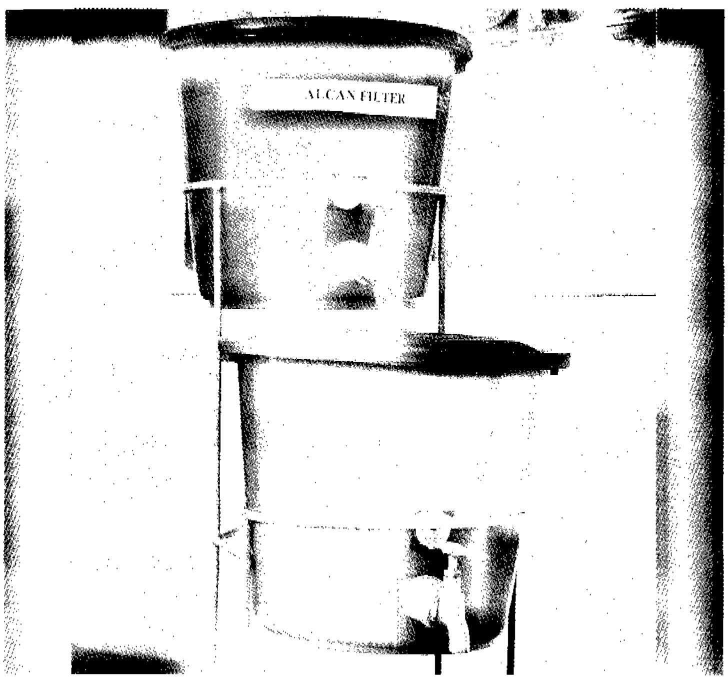

Fig. 1: A typical Alcan filter setup

OBJECTIVES

The major objectives of this study were to: (i) assess arsenic removal efficiency from contaminated water within WPP area, (ii) find out the breakthrough point of the medium so that the minimum life-time of a filter within a certain level of contamination can be worked out and (iii) conduct social acceptance in the community.

METHODOLOGY

For both removal efficiency test and social acceptance studies, 5 households were selected based on their ability to pay at least 20% of the actual cost of the filter set. Three fixed tube-wells were chosen for feed water in a severely affected area. One filter was installed next to a tube-well whose arsenic concentration varied over time. Also, there were two more filters installed at WPP Laboratory for simultaneous monitoring purpose.

Water quality parameters such as arsenic, iron, pH, turbidity and fecal coliform count were measured during the study. Samples were collected, analyzed and reported according to the standard protocols. Acceptability study was conducted through individual interviews and focused group discussions (FGD) with the users in the community. A wide range of activities such as training on operation and maintenance, collection of large quantity of feed water from a contaminated area for laboratory use, and preparation of field questionnaire survey were a few to cite that encompassed the action research. Monitoring of the water quality was also a critical aspect of the study.

RESUTLS AND DISCUSSIONS

Laboratory test

Two sets of filter installed at WPP laboratory went under rapid assessments. Both modeled and naturally contaminated waters were used for this purpose. The assessment basically included monitoring of the water quality for 14 days for both laboratory and field water. Standard water quality parameters were thoroughly investigated. However, of the primary concern, arsenic test results show that for both types of water the efficiency of removal remained quite high in between 88% and 98% with raw water concentration levels in between 1990 µg/L and 104 µg/L. There was hardly any difference in removal efficiency because of changing concentrations from low to high levels. However, the allowable limit of arsenic in drinking water i.e. 50 µg/L determines the limit of maximum arsenic concentrated water to be used for treatment. Assuming an average efficiency of 90%, it can be said that raw water having arsenic level less than 500 µg/L can be used for treatment on average.

pH of the treated water was initially found in the acidic region as low as 5.5 with a range of 4.9 - 6.6, whereas the pH of the raw water was around 7.0. However, later it was evidenced from the field study that pH of the treated water rises up to normal after few weeks of continuous use.

The filter showed high performance in reducing turbidity from raw water. In most cases, the raw water had higher turbidity in the range of 25-125 NTU, whereas the desired level is only 15 NTU. The filter clarifies highly turbid water and brings the level less than 5 NTU with ease.

In regard to the biological quality of treated water, it was found that the filter medium does not abet the growth of microorganisms. However, it was not clearly seen whether the medium could filter these organisms, if present in the raw water. Couple of tests showed a slight decrease in number of coliform forming bacteria, although the filter could not eradicate all of them after treatment.

Field Assessment

5 filters installed at 5 households were monitored for 3 months on regular basis. Samples from each household were collected and tested at the laboratory for tests of routine chemical and biological parameters.

Arsenic removal at household was similar to the findings from the rapid assessment in the laboratory. The arsenic removal efficiency

(%) was in the range of 84-92% with an average of 88%. During the monitoring period, concentration of arsenic in the treated water was never found exceeding the allowable limit.

In addition to arsenic, iron removal efficiency was also measured with the field samples. As it would be expected, iron removal was also high with an average of 89%. This reduction of iron content in drinking water surprised the users, who often face the persistent problem of iron coloration in this region. As a result, users liked this filter, which was noted during questionnaire survey.

pH and turbidity of the water were also found to be similar to the results found in the laboratory experiment.

Contrary to the findings in laboratory, biological parameter study showed mixed findings during field operation. Some of the treated water samples showed presence of fecal bacteria, which perhaps, were due to secondary contamination. However, some samples showed substantial removal of pathogens through the medium.

Breakthrough point experiment
The breakthrough point, when arsenic finds its way into the treated water through the medium in an excess amount of 50 μg/L, experiment provided information about the lifetime of the filter medium. During this experiment, tube-well water was passed through medium continuously. From this experiment, it was found that a filter can treat up to 11500 L of arsenic contaminated water provided that the water contains arsenic less than 311 μg/L with an average removal efficiency 81% (Fig. 2). With this statistics, if a family uses 30 L of water per day, the filter will last for a year without changing the medium

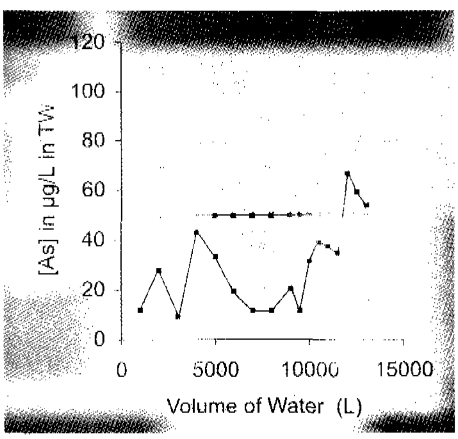

Fig. 2: Determination of arsenic breakthrough point (also shows the corresponding removal efficiencies)

It is here to be noted that the variation in removal efficiency with the variation of water amount is not significant. Rather, it is hard to deduce any conclusion regarding the removal efficiency loss. On the other hand, it is more important to recognize arsenic level in treated water than to loss of efficiency. Sometimes even high removal efficiencies may result in arsenic level higher than the allowable limit in the treated water.

Social aspects
The filter operation mechanism is simple and easy and it is not labor intensive at all, in compare to other filter systems available in the market. Users are particularly happy about the high discharge rate, which is not usual for a traditional filter. The rate is as high as 15 L per 15mins. As a result, almost all of the users expressed their satisfaction about the filter. However, people cast their doubts about the maintenance and availability of the filter medium once they exhaust. They think that the parts of the bucket set might break down after a month or so that will enhance the maintenance cost and the filter medium, although rechargeable, is still not available in the local market. In addition, high purchase cost also accounted for the discredit of the filter. Although beneficiaries paid only 20% of the actual cost of Tk. 2000/- per set, they are unwilling to pay the full cost of the technology. Monitoring of the water quality is another point, where people raised question i.e. who will conduct the tests and how.

LIMITATIONS

This filter system is also subject to several pitfalls. Firstly, the initial treated water has a bitter, metallic taste and the pH is usually high at the beginning. Because of this characteristic, people may refrain from using this filter. Although no immediate complains concerning health was received, the cumulative impacts of residual chemicals in the treated water are yet to be assessed. There are some mechanical demerits of the system; the joint at the faucet can break frequently resulting in leakage of water from the bucket and the bucket might be broken due to hardening of the plastic for long time use.

RECOMMENDATIONS

The filter option had enough merits to be introduced at the field level. The treated water complied with the required standards, and the cost of maintenance is also low.

The spare parts as well as original filter sets should be available in the market so that potential users can easily get access to them. The system may also be promoted for iron removal purpose in areas where iron is a major problem.

A study on residual aluminum in the treated water should be conducted before wider application of the technology. Again, mass scale application needs to develop a good monitoring system on water quality.

FEATURES OF ALCAN FILTER

Removing metal ions	As, Fe.
Avg. removal efficiency	As (90%). Fe ([illegible]
Capacity	1 liter per min.
Taste of treated water	Good.
Availability	Not available in the local market. Available only through an agent in Dhaka.
Installation cost	Tk. 2000/-.
Material recharge time	Depends on arsenic [illegible] water and use pattern.
Advantages	Simple and easy operation and maintenance etc.
Limitations	Leakage through the joints, bitter water taste at the beginning costly etc.

Note: Community based Alcan Filter is also available.

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Shapla Filter

INTRODUCTION

Shapla is a household based arsenic removal filter that is solely manufactured in the local market using available technology and ingredients. The filter has been developed and promoted by International Development Enterprises (IDE), Bangladesh, also one of the INGO partners in WPP.

The key ingredient of the filter media is iron-coated brick chips prepared by treating with ferrous sulphate solution. The filter device itself is a burnt earth pot of capacity of around 20 L. The assemblage of the filter is shown in Fig. 1.

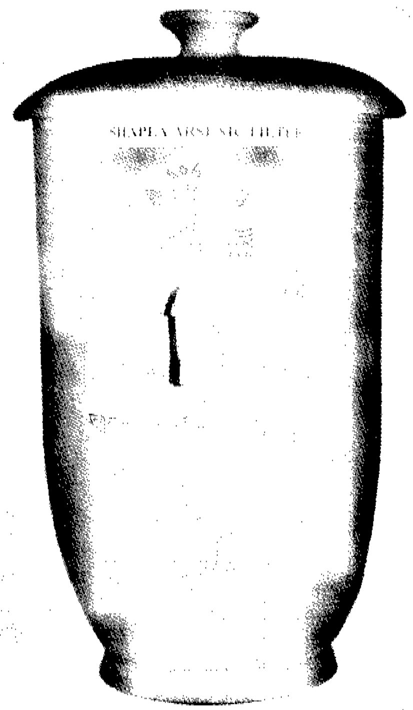

Fig. 1: Shapla arsenic removal filter

The experimental units have been installed for field testing in selected households in Satrajitpur village, one of the worst arsenic affected areas in WPP, under Shibgonj thana of Chapai Nawabgonj district following the recommendation put forward after a short-term rapid assessment in the laboratory.

OBJECTIVES

The following objectives were set to:

- study removal efficiencies of Shapla filter with a single charge of media.
- investigate users' social acceptance of the technology.
- investigate the limitation of the system, and hence,
- make recommendations for further improvements, if requires.

STUDY PERIOD

The study was carried out on performances of 20 Shapla filters installed in 19 households for 6 months from August 2002 to February 2003.

METHODOLOGY

19 households were selected based on the family size, arsenic contamination level in their water sources, and willingness to share cost (50% of the actual cost) of the system. 20 filters were installed in two successive days at suitable locations of the participating households. During installation the users were oriented on operation and maintenance of the filter.

Samples were collected, stored and preserved in well labeled and tightly capped clean acidified HDP bottle following the standard method for water samples.

The physical parameters including color, odor, taste, turbidity, and pH of both raw and treated water were tested on the spot. The chemical parameters including arsenic and iron were tested both at field and at WPP laboratory.

The monitoring activities were systematic: visit to the households to see the functionality of the system once in every week, understanding users' feeling about the system once in a month and an assessment study in the 1st and last month during the research period.

RESULTS AND DISCUSSIONS

In general, users have appreciated color, taste and odor of filtered water as the findings suggest, although at the beginning some of the users complained about 'brick sand' smell of treated water for a couple of days after installation. However, later they agreed that the smell went off as the media clears up after successive uses.

The pH of the treated water was found to increase from its level in the raw water for 1st few days, although later pH of filtered water came down to an acceptable limit. The pH varied between 6.8 and 8.3.

Shapla filter removes turbidity from tube-well water efficiently. Water having turbidity in the range of 5 to 130 NTU, was always cleared through the filter. In all cases, the final reading was below 5 NTU, the desired level of turbidity in drinking water.

Analysis of test results from 20 filter sets shows that Shapla filter has high efficiency to reduce arsenic from original level. It was found that the removal efficiency varied from 86% to 96% for arsenic concentration range of 70 to 659 μg/L in raw water. An attempt was made to correlate removal efficiency with raw water arsenic levels (Fig. 2). However, any reasonable correlation is hardly seen (R^2=0.5743). It is, perhaps, fair to conclude that it is the arsenic level in treated water that is more important than the mere removal efficiencies. Because, our objective, at any cost, is to achieve arsenic level in filtered water below the Bangladesh Standard level.

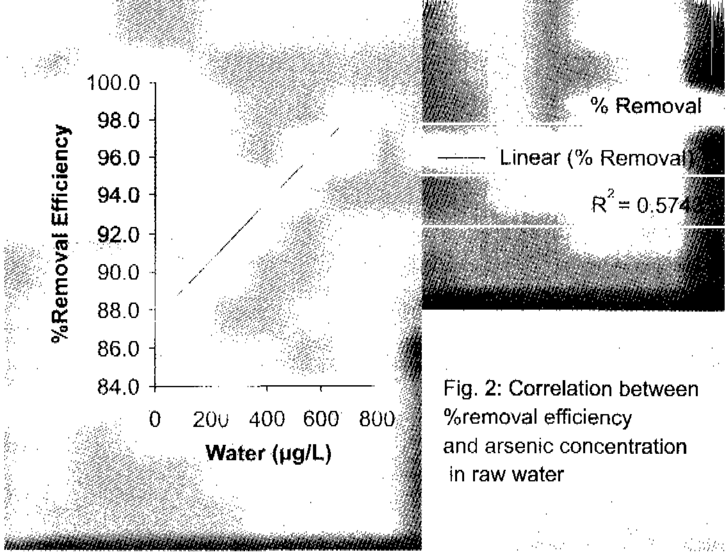

Fig. 2: Correlation between %removal efficiency and arsenic concentration in raw water

Further a correlation between the levels of arsenic in raw and treated waters was also studied. Fig. 3 shows that there is hardly any correlation between these variables. However, one thing is clearly evidenced that arsenic levels in treated water never exceeded the allowable limit when the arsenic levels in raw water varied from 70 to 659 µg/L. It is also understood that Shapla filter can remove high level of arsenic in tube-well water.

Although having high removal efficiencies, these filters suffered from reduction in efficiencies over time. As a result the media becomes unusable when arsenic breaks through to filtered water in access of allowable limit. It was reported that the saturation points of these filters vary from as little as 4 weeks to 8 weeks. However, there are several factors that determine the lifetime of the filter media. It was also corroborated from this study; 5 filters were found saturated within 3-6 months, whereas the rest 15 filters are still running effectively with the single charge of media till February 28, 2003 since installation.

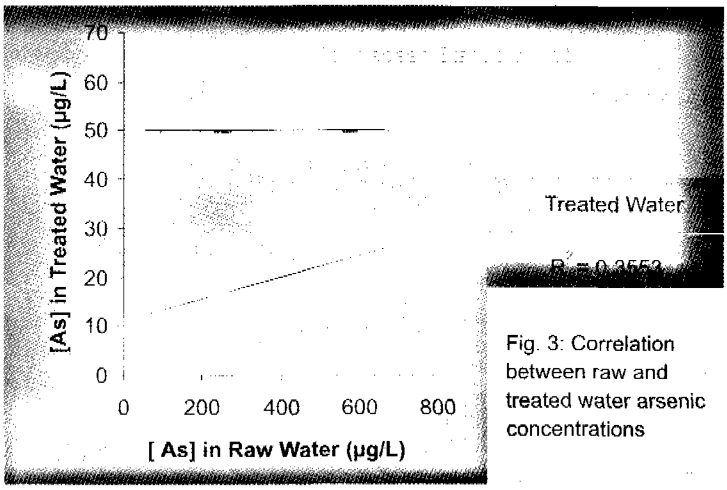

Fig. 3: Correlation between raw and treated water arsenic concentrations

One of the elements that causes turbidity in tube-well water is the dissolved iron. It was found that Shapla filter also acts on iron effectively. The average iron removal efficiency of the system is as high as 99%. From analysis, it was also seen that raw water having 0.3-9.4 mg/L of iron becomes almost totally iron free after filtration.

Filtered water quantity

It has been claimed that 20 kg of Shapla filter media can filter 1400-4798 liters arsenic contaminated tube-well water to acceptable limit based on the arsenic concentration in raw water, family size, requirements and above all the quality of the filter media.

Establishment of private sector supply chain

Development of a private sector supply channel for the filter system is very important factor for sustainability of any mitigation option at the field level. In this regard, a special initiative has been taken to develop a local potter and dealers linking them.

ADVANTAGES

Shapla filter has several advantages including:

- cost effective and feasible for 5-6 member families.
- simple and easy operation and maintenance.
- provision of color, taste and odor free water.
- can also be used as iron removal unit.
- home based option, so better for women since they are the ultimate water collector, need not to go out for water collection.

LIMITATIONS

Some limitations of the filters have been reported as follows:

- arsenic removal efficiency varies from media to media of this system.
- container may crack and leakage problem may arise at the bottom.
- in winter, filter water becomes too cold in comparison to tube-well water

CONCLUSIONS AND RECOMMENDATIONS

The available information dictates based on the 6 months action research program that the unit is effective in arsenic and iron removal. The manufacturing cost is also reasonable. So, it is recommended that WPP should use this option as an immediate response to the emergency arsenic mitigation measures.

FEATURES OF SHAPLA FILTER

Removing metal ions	As and Fe (tested)
Avg. removal efficiency	As (91%), Fe (99%)
Capacity	20 Liter per day.
Taste of treated water	Odor free, and tastes good.
Availability	Available in the local market.
Installation cost	Tk. 460/- per set. Tk. 60/-per 20 kg of media materials.
Material recharge time	Depends on arsenic level in raw water and use pattern.
Advantages	Affordable, simple and easy operation and maintenance etc
Limitation	Leakage at the bottom of the filter, "bricky" smell at the beginning etc.

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Solar Disinfection (SODIS)

INTRODUCTION

SODIS (Solar Water Disinfection) is a low-cost water treatment method to improve the microbiological quality of drinking water at household level. In this process, PET plastic bottles are filled with contaminated water and exposed to sunlight for a day. Because of the UV-A radiation and increased temperature in the bottle, microorganisms are inactivated (Fig. 1). Then the bottle is left standing on a flat surface overnight and the supernatant clear water is passed through a cloth filter in the morning. Finally, the water is ready for consumption. The key requirement for the treatment option is only transparent bottles, which makes it cheap. SODIS has been applied elsewhere in the world. WPP took a piloting of this option as an alternative arsenic mitigation option with the technical assistance from SANDEC- EAWAG, Switzerland.

Because of the appearance of arsenic in groundwater, alternative water sources and arsenic treatment processes are being developed. One possibility of such options is to use surface water in the area where groundwater is contaminated. However, in most cases surface water is not safe for consumption and, therefore, requires disinfection.

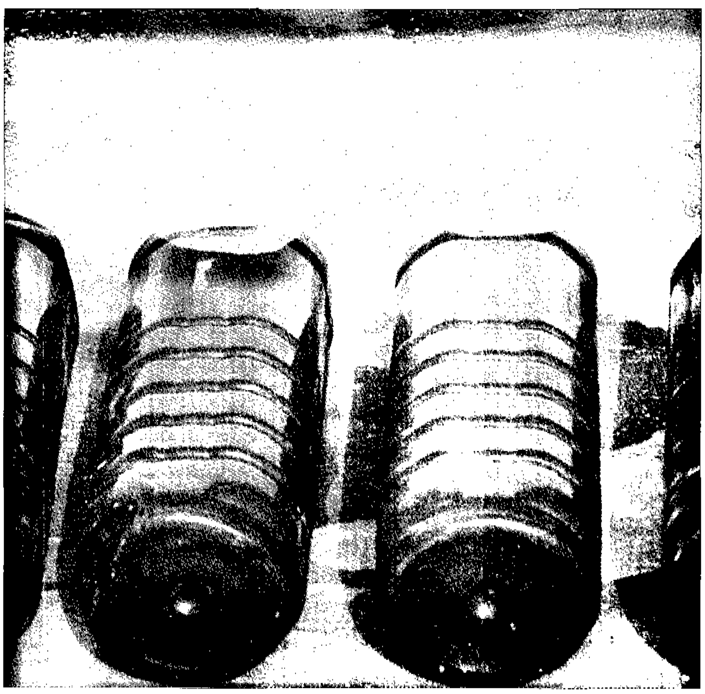

Fig. 1: SODIS set-up

16 villages within WPP participated in the SODIS experiment. In each village, 10 households were selected during the first phase of SODIS implementation in the area. Only 3 out of 16 villages were affected by Arsenic. Tubewell water in the other villages was not affected or not tested for arsenic content. Villages differed widely from each other in terms of water availability, arsenic contamination, and economic situation. In this action research SODIS as a source of alternative water has been studied.

OBJECTIVES

SODIS action research was aimed at to: (i) introducing a treatment option for surface water at household level, (ii) feasibility study of SODIS application in arsenic contaminated areas and (iii) improving the SODIS technique.

METHODOLOGY

Water quality tests in sentinel households were performed to assess SODIS efficiency in the field. Additional water quality tests have been performed in households of regular SODIS users. Samples of treated water from SODIS bottles, as well as samples of the corresponding raw water were examined for fecal coliforms with the DelAgua field test kit (OXFAM) in the WPP Laboratory. In the selected households, water temperature was measured 3 times a day over an average period of 4.5 hours, which is the minimum duration of sunlight exposure to ensure efficient water disinfection. Tests were performed during the period from January 2000 to April 2000.

Interviews and general observations as well as informal discussions were carried out in order to assess SODIS use and villagers understanding, water use and perception of the arsenic crisis. In-depth interviews were performed with a semi-structured questionnaire in randomly selected 7 villages with a total of 100 households (50 SODIS users and 50 non-users). Topics of the questionnaire included general concerns, health concerns, causation, water usage pattern and perception of SODIS, water quality and arsenic contamination. Furthermore, a monitoring of air-and water temperatures was conducted 7 times daily for one year (April 99 to April 2000) using 2-3 SODIS bottles on the roof of the office building in Rajshahi.

RESULTS AND INTERPRETATIONS

Technical aspects

In 84% of the measurements, sun was at least partly present, showing that the amount of sunshine in the study area does not seem to be a restricting factor for SODIS. Water temperature within the SODIS bottle reached 50°C and more in 20% of all measurements in the dry season. In winter, approx. 80% of the measurements indicated temperatures barely reaching 40°C. Considering all seasons and weather conditions, a water temperature of 50°C could be reached in 11.4% of all cases (82/718). In the wet season, approx. 75% of the measurements was over 40°C, though fully clouded sky or rain occurred during 28.1% of the measurements. This shows the dry season to be the best season to use SODIS. Though temperatures were also high during wet season, frequent clouding and rain might hamper proper SODIS use.

Bacteriological examination showed various results. In general, findings show tube-well water to be of low contamination, if any (<20 CFU/100ml), where dug-well water is more contaminated (>80 CFU/100ml). Ponds and rivers were highly contaminated (>3000 CFU/100ml) by fecal coliforms. In a large part of the samples examined, SODIS was not able to disinfect the water completely, though a reduction was most often achieved. Smaller efficiencies were often caused by inadequate application of SODIS. Temperature, degree of contamination, time and duration of exposure were not found to correlate. This might have partly be due to the small sample size, the use of SODIS in the field or unidentified problems during water analysis. Focussing on regular and consistent users of SODIS, results of the bacteriological analysis were more convincing than the findings in the sentinel samples. The user samples were collected in dry season (May), where the sentinel samples were collected in winter season (Jan/Feb). Although higher in the user samples, mean water temperature between the 2 groups did not differ significantly.

This suggests that the seriousness and practice by which people use SODIS (bottles exposed in the shade, incomplete bottle cleaning) might also play an important role in the efficacy of SODIS. Further factors included correct training and close supervision as was previously observed in other parts of the world (e.g. Indonesia).

Table 1 shows the results found during the in-depth interviews with the users of SODIS. It was reported that two thirds of the users claimed to need more bottles. Their estimate number of bottles needed was in average 10.5 nos. per family, resulting in a coverage rate of 2.33 nos. per person. Availability of PET bottles in the region is scarce, hampering the proper supply to the villages. This constrains further implementation of SODIS in the villages and long-term, sustainable use of SODIS.

Table 1. Frequency of expressed problem with bottles or reasons for exchanging bottles. In brackets: proportions. (Source: In-depth interviews, Dec 1999)

Problem or Reason of exchange	Frequency (mentioned as problem)	Frequency (reason as problem)
Cap Loss	77.8% (35/45)	
Smell	4.4% (2/45)	
Color Loss	77.8% (35/45)	
Deformation (cracking) due to heat	20% (9/45)	52.4%(11/21)
Dirty	11.1% (5/45)	33.3% (7/21)
Cracking due to roof fall	8.9% (4/45)	23.8% (5/21)
Transparency loss	2.2% (1/45)	23.8% (5/21)
No problem	11.1% (5/45)	

The extensive heat and its effects on the bottles during exposure were mentioned as a reason to exchange bottles in more than 50% of the responses. Although temperature was not shown to rise above 50°C very often, it might already be enough to damage bottles after long or repeated exposure. Deformation is further problematic as the cap can loosen resulting in leaks and cap-loss. Furthermore, cap-loss considerably hampers SODIS use. In addition to the problems listed in Table 1, socio-cultural problems contribute significantly to the acceptability of SODIS in the field.

Socio-cultural aspects

During the socio-cultural study of SODIS, users and non-users in both arsenic affected and unaffected villages were interviewed. The introduction of SODIS was not based on a felt-need on part of the communities as illustrated in the observed irregular usage patterns of SODIS.

The fear for arsenic in most communities was high and often a major motivation to use SODIS, even if the village is not affected by arsenic contamination of groundwater. However, there were people showed fatalistic views about arsenic contamination, who were also indifferent to SODIS use.

People found to be more comfortable with tub-well water or dug-well water for SODIS use than the pond water. It was hard to motivate people to use pond water for SODIS. Considering all villages, 81.1% of the households under study claimed to drink tube-well water, 14.5% consumed dug-well water and 4.4% SODIS water at the time of interview (April 2000).

RECOMMENDATIONS

Based on the findings from the action research, SODIS was not recommended as an option to be widely used in WPP area as part of arsenic mitigation measures. It was due to the high scarcity of required number of bottles as well as people's overall indifferences to the option. The locally available PET bottles could not be supplied in sufficient numbers (e.g. 2-4 bottles per person) and they lasted for a period of 4-6 months only as they were deformed by heat, got dirty or lost their caps. People also see the operation and maintenance of the option as extra work and cumbersome in their daily life

FEATURES OF SODIS

Disinfection	Mainly pathogens in water.
Efficiency	Depends on the conditions of raw water for SODIS.
Capacity	1.4 L/2.0 L PET bottles are used. The number varies depending on requirement.
Taste of water	Good.
Availability	Bottles are not available in large numbers in the village level.
Cost	Used PET bottles may cost Tk. 4 - 6/- per bottle.
Advantages	No chemicals used, can be used as complementary with other options etc.
Advantages	No chemicals used, can be used as complementary with other options etc.
Limitation	Short life of PET bottles, variable sunshine, scarcity of bottles etc.

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Terracotta Filter

INTRODUCTION

'Terracotta', meaning 'made of earth', filter was invented and developed in Orissya, India in order to treat surface waters for pathogen free drinking water supply in rural areas. This is a low cost technology made of ordinary pottery silt clay, sand and sawdust. The filter can be fitted into any water pot either metallic or non-metallic chambers, buckets etc., depending on the availability of them in local markets (Fig. 1). This system presumably filters pathogens from water and makes it fit for drinking and cooking.

WPP received two terracotta filters from Unicef, Delhi through PMU for considering this filter as one of the options at field level within its project areas.

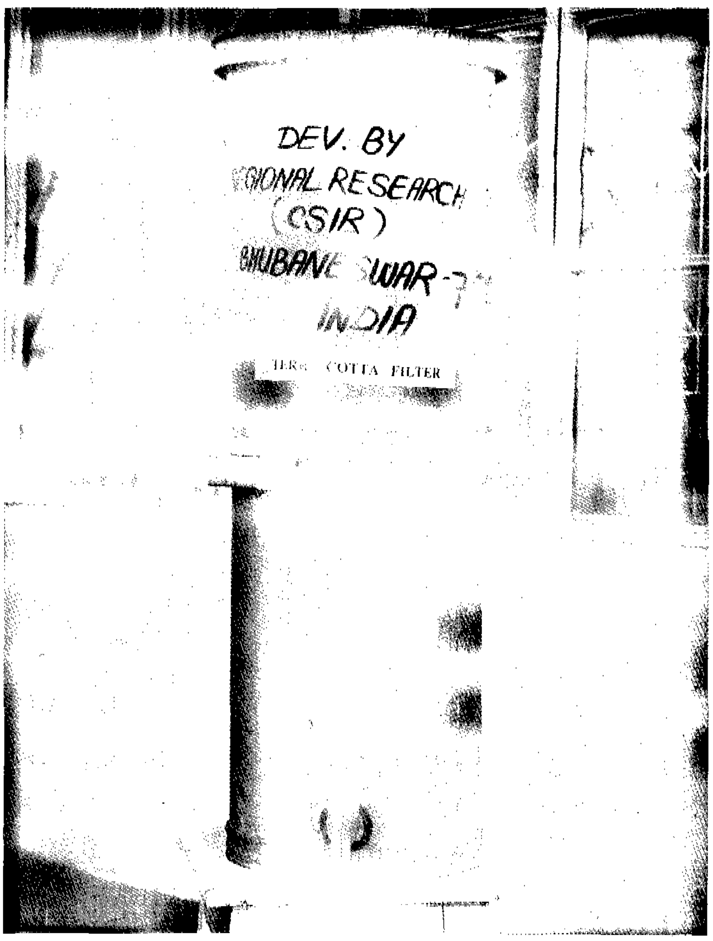

Fig. 1: Terracotta Filter

OBJECTIVES

This study aimed at to investigate the efficiency of this filter including rate of discharge, removal of iron and the major concern bacteria from raw surface waters. Finding out limitations of the system and to recommend whether to adopt this new option in WPP area or to reject all together- were also the integral parts of the action research objectives.

METHODS

Water from different sources including pond, dug-well and river were treated through this filter. Source water was collected in medium size plastic drums (37 L capacity). For bacteriological test, water samples were collected in sterilized glass bottles. Parameters measured during the test period were essentially the minimum parameters required to describe 'water quality': pH using a electronic pH meter, Turbidity with DelAgua field turbidity meter, Iron (Fe) by HACH method using small pillow of sodium metabisulfite at 510 nm of wavelength. For the bacterial contamination measurement, colonies of indicator bacteria were counted using DelAgua field test kit using sodium lauryl sulfate broth media.
The upper tank of the filter was filled with 17 liters of raw water and the discharge rate of the filter was recorded in every six-hour interval.

Only treated water was disinfected with commercial bleaching powder containing 33% of free chlorine, whenever needed.

RESULTS AND DISCUSSIONS

Physical and Chemical Aspects

Because of high content of debris, the pH of the surface water is usually always high, compared to tube-well water. In this experiment, it was also evidenced that pH of pond water was as high as 9.2. After passing through the filter medium, the pH changed slightly in the order of 0.7 to 1.1. Unlike pond water, dug-well water showed an acceptable pH range for drinking water around 7.5 for both raw and treated water. It was reported that the untreated pond water always had high turbidity compared to other water sources. Pond water turbidity varied from 35 to 65 NTU, whereas turbidity of dug-well and river water varied from 8 to 13 and up to 10 NTU respectively.

Terracotta filter reduced turbidity of the source water quite significantly, although different sources had different turbidity as stated above. It was seen that the turbidity of the treated water was brought down to 5 NTU after treatment, clear enough to drink for all types of feed water.

Iron (Fe) was also measured both in raw and treated waters. The level of iron in pond water varied from 0.01-0.25 mg/L. In comparison, the levels were lower in dug-well and river waters. However, for all types of test waters iron was removed at an efficiency of 88 to 100%.

Counts of fecal coliform of raw water varied from 13,400 to 640 cfu[a] per 100 mL in pond water and 2700 to 46 cfu/100 mL in dug-well water, while river water had 3820-1400 cfu/100 mL. The filter removes bacteria at a high level of efficiency from 100% to 70%. The average efficiency was 87.6%. The average bacterial removal efficiencies of the two filters with different water sources are given in Table 1.

a. coliform forming unit

Table 1: Bacterial removal efficiency of Terracotta filters

Water	Filter	Average Bacteria (cfu/100mL)		Average Removal Efficiency
		Raw water	Treated water	
Pond-1	F-1	7800	1071	84.0
	F-2	7733	1003	84.8
Pond-2	F-1	1393	230	82.8
	F-2	2131	345	82.6
Dug-well	F-1	1346	259	92.1
	F-2	2223	214	86.8
River	F-1	2840	167	93.5
	F-2	2973	165	94.3

For making water completely free of bacteria, bleaching powder was added in the treated water. From this disinfection study it was found that a small dose 0.01g of bleaching powder (33% Chlorine) was enough to disinfect one liter of treated water.

Discharge Rates

The discharges through the filter decreased over time (Fig. 2). The trend, although expected, is due to the clogging of the filter medium with suspended particles present in surface waters. On an average over 15 days of operation, it was found that only 1.26 L/day was filtered through the media.

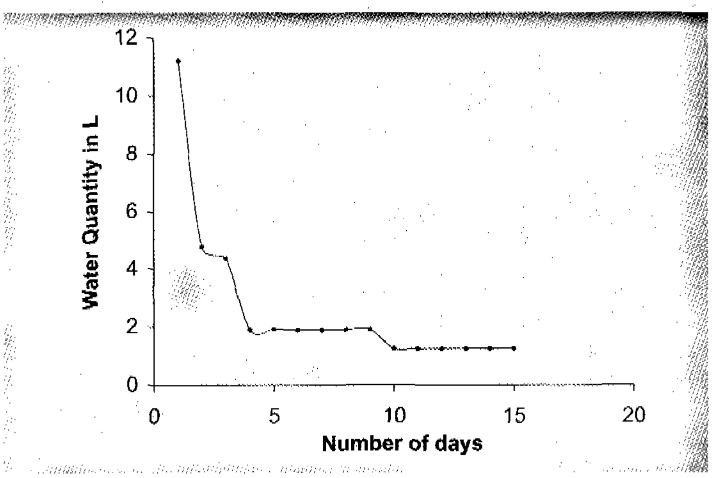

Fig. 2: Variation trend in discharge rates through terracotta filter for pond water (turbidity 35-65 NTU)

OBSERVATIONS

The terracotta filter is an easy technology that can be easily used by the villagers. From study, it was observed that the filter could produce sufficient water for 6 to 8 member family, only if dug-well or river waters are used. Pond water clogs the media quickly, as the turbidity of pond water is always high. The filter can tackle high turbid water, but suffers performance drawbacks shortly. This filter can remove 88-100% iron from surface waters. Terra-cotta filter cannot remove 100% Coliform bacteria from surface water of pond, dug well and river, so requires bleaching treatment. Washing of filter materials with brass is needed everyday to remove the clogging materials.

CONCLUSION

Although terracotta filter has some advantages like easy handling, high iron and turbidity removal efficiencies and sufficient discharge rates for dug-well and river water, however, this filter is not suitable for supplying pathogen free surface water for drinking purpose. The terracotta filter could not eradicate bacteria completely. The average bacteria removal efficiency of terracotta filter was 83.5% for pond water, 89.4% for dug-well water and 93.9% for river water. The addition of small quantity of bleaching powder can improve the water quality and 100% disinfection might be possible.

RECOMMENDATIONS

The filter needs further improvement to ensure complete removal of bacteria from high content of pathogens, as was the case for pond water.

If used in the field level, one should add a small quantity of bleaching powder (33% chlorine) to the filtered water to get complete eradication of bacteria from source water.

Considering its bacteriological improvement capacity without bleaching power and low discharge rates, the filter was not recommended for further field-testing in WPP area.

FEATURES OF TERRACOTTA FILTER

Major function	To remove bacteria.
Others	Removal of Iron (Fe), suspended solids etc.
Avg. removal efficiencies	Approx. 80% for bacteria, and approx. 80-100% for iron.
Discharge rates	Variable, but for two-week period average is 1.26 liter per day (without scrubbing).
Taste of treated water	Good.
Availability	Not available at local market.
Material recharge time	Not known.
Advantages	Simple and easy operation if low-turbidity water is used.
Limitations	Low discharge rates, requires chlorination for complete removals of bacteria, and demands frequent cleaning, if high-turbidity water is used i.e. pond water.

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Rural Piped Water Supply Piloting

INTRODUCTION

In the context of the arsenic contamination in the shallow groundwater, a long-term sustainable water supply system is the present demand and piped water supply is considered as a feasible option for the following two reasons:

Technical reason: The arsenic concentration has a seasonal variation effect and the concentration may increase within a certain time period. It created the need to check the arsenic level in the groundwater source on routine basis i.e., at least twice in a year. If water is supplied from one source (with or without treatment) in a village, it is possible to monitor the water quality in one point rather than surveying hundreds of sources in a village.

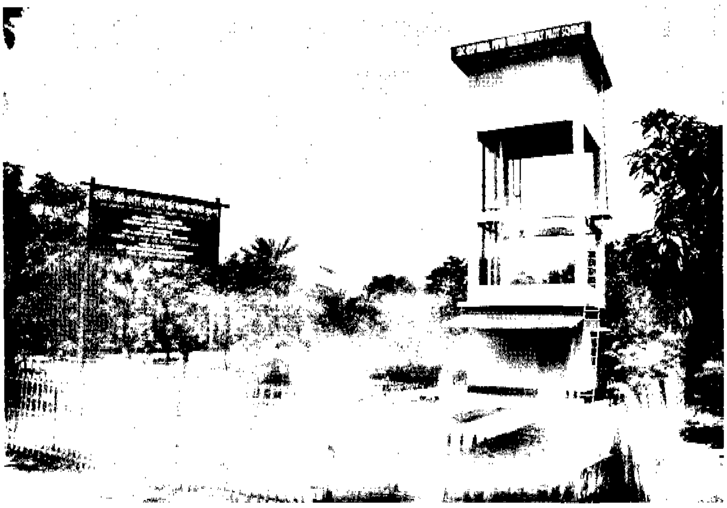


Fig. 1: Overhead Tank of Piped Water Supply System

Socio-economic reason: The willingness to pay assessment conducted by WSP-BRAC indicates a strong willingness to pay for piped water connections to households. This is due to the villagers desire for better level of service, influenced by the development taken place in rural areas.

Rural piped water supply scheme is a piloting scheme in the WatSan Project area in collaboration with the Water and Sanitation Program (WSP) of the World Bank. It is located at the Horirampur Village under the 4 Nos. Monigram Union Parishad of Bagha Upazilla under Rajshahi district. The cost of the physical infrastructure has been jointly contributed by the SDC (80%) and community (20%).

The overall key challenge of the piloting is to ensure smooth operation and maintenance at the community level with 100% cost contribution. The piloting is the partnership of local community, union parishad and partner NGO. The SDC and WSP has provided the technical assistance in design, implementation and capacity building.

COMPONENTS OF PIPED WATER SUPPLY SYSTEM

A typical piped water supply consists of a water source (river, lake, production well for ground water), water treatment plant (if required), overhead water tank and distribution pipelines. The Fig. 1 shows the overhead tank of the piped water supply system in Horirampur.

Table 1: Technical Details of Piped Water Supply Scheme

Test well- 2 Nos.		
	Size	38 mm dia
	Depth	60 m
Production Well		
	Size	100x150 mm dia
	Depth	60 m
Pump		
	Type	Submersible (Pedrollo), 4 inch dia, 3 H.P.
	Power	Single phase (220-250 volts)
	Flow rate	800 liter/min
Overhead Tank		
	Capacity	24,000 liter
	Top level	12 m from GL
	Delivery pipe	4 separate delivery pipe for individual para
	Overflow pipe dia	50 mm
	Washout pipe dia	50 mm
Pump House		
	Available floor space	14.5 sq. m.
Piping Network (total 5244 m pipe line)		
	100 mm dia pipe	526 m
	75 mm dia pipe	1082 m
	50 mm dia pipe	2424 m
	38 mm dia pipe	166 m
	20 mm dia pipe	1038 m
	100 mm dia gate valve	4 Nos.
	75 mm dia gate valve	3 Nos.
	50 mm dia gate valve	6 Nos.
Total House Connection		
	Present Connection	134 Nos.
Treatment Unit		
	Treatment Unit	No treatment unit (Provision for future construction)

OBJECTIVES

The objectives of the action research were to: (i) monitor the water quality parameters, (ii) assess social acceptance of the technology, and (iii) evaluate the community's capacity in operation and management.

METHODOLOGY

Water samples were collected periodically according to standard sampling protocol. The samples were collected in three different points of the piped network. The samples were tested at the WPP laboratory following the standard method of testing. The physical parameters are pH, temperature and turbidity. The chemical parameters are ammonia (NH_3), arsenic total (As_{tot}), chromium (Cr), fluoride (F^-), iron total (Fe_{tot}). The biological parameters included the test of fecal coliform.

The users' reflection on the water quality, quantity and overall operation and maintenance issues were collected through personal interviews. 45 nos. of users were interviewed on the above mentioned issue.

The community's capacity in operation and management is judged by reviewing the progress report, physical observation, and discussion with the VDC leaders, users, local NGO and Union Parishad Chairman.

RESULTS AND DISCUSSION

Water Quality

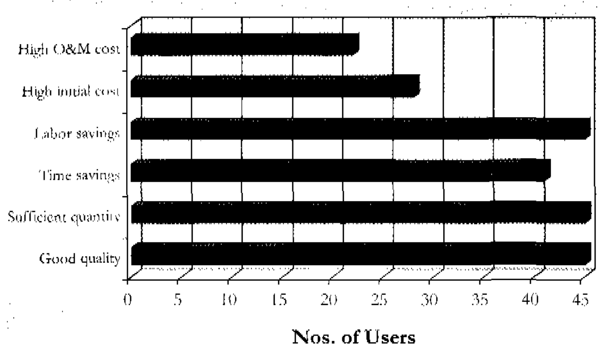
The average water quality results are presented in the Table-2 along with the Bangladesh standard and WHO guideline value. The results are almost consistent over three periods of measurements. All the tested water parameters are with the acceptable range.

Table 2: Water Quality Parameters

Sl. No.	Name of the Parameters	Pipe water Harirampur	Bangladesh Standard	WHO Guideline
	Physical Parameters			
	pH	7.2	6.5-8.5	6.5-8.5
	Temperature	28.8° C	20-30° C	-
	Turbidity	00 TU	10 TU	5TU
	Chemical Parameters			
	Ammonia (NH_3)	0.087 mg/L	0.5 mg/L	1.5mg/L
	Arsenic Total (As_{tot})	0.007 mg/L	0.05 mg/L	0.01mg/L
	Chromium (Cr)	0.01 mg/L	0.05 mg/L	0.05mg/L
	Fluoride (F^-)	0.4 mg/L	1.0 mg/L	1.5mg/L
	Iron Total (Fe_{tot})	0.18 mg/L	0.3-1.0 mg/L	0.3mg/L
	Biological Parameter			
	Fecal Coliform	00 CU	00 CU	00CU

Users' Acceptance

Users have well accepted the technology, because of its advantages over the traditional handpump technology. The taste of the water is good, acceptable iron in the water, available in sufficient quantity, reduces the water collection time and labor. Despite the advantages, some noticed that the initial cost and operation and management cost is high compare to the existing water supply through handpump. The preconceived idea about getting free water supply by government due to arsenic problem further discouraged to cost contribution. Again, regular monthly payment for O&M seemed extra burden to some people. These obstacles are gradually fading out through the benefits getting out of the system network. The Fig. 2 shows the major interview findings.



Community Capacity in O&M

Though a community managed water supply system suffer different initial obstacles, but it seemed that community are capable to maintain the system. The community carried out the land registration and electricity connection with the minimal support from partner NGO. Communities showed their ability to operate and maintain the system by 100% community contribution over eight months of period. The skill development training for the caretakers has brought significant impact. They can solve the minor technical problems in the networks, house connections or even electric switch. A network has been established with the private sector so that they can directly contact for types of technical requirements.

CONCLUSIONS AND RECOMMENDATIONS

It has been revealed that the piped water supply scheme is technically feasible option. It provides opportunity not only to monitor the arsenic and bacteriological water quality, but also the other major water qualities. The piped water supply has the benefits in the provision of water supply over the handpump tube-well but have the challenge to manage efficiently involving the community and the local government institutions. The expectation of free water supply in the arsenic contaminated areas has impeded the smooth operation in few instances. Some users were reluctant in regular payment of monthly O&M cost. However, the benefits of the system and awareness campaign are progressively reducing the attitude and they have started to consider the economic value water.

The piloting in Horirampur has encouraged the other villagers and some of the village development committees have come forward to implement the scheme in their village on cost sharing basis. A few more piloting is required before up scaling rural piped water supply in massive scale.

FEATURES OF PIPED WATER SUPPLY SCHEME

Installation cost	Approx. Tk. 200,000.
Recurrent cost	Approx. Tk. 3,000 (per month).
Family coverage	Presently 134 connections can supply more than 500 connections.
Taste of water	Widely accep[illegible] the people.
Arsenic content	Arsenic is within WHO and Bangladesh acceptable limit.
Other parameters	Other parameters within WHO and Bangladesh limit.
Fecal coliform	Nil at different supply points.
Advantages	Monitoring single source can ensure water quality. Safe water is available in required quantity. Reduces the time and labor for water collection.
Limitations	Strong community motivation is pre-requisite for success of piped water networking.

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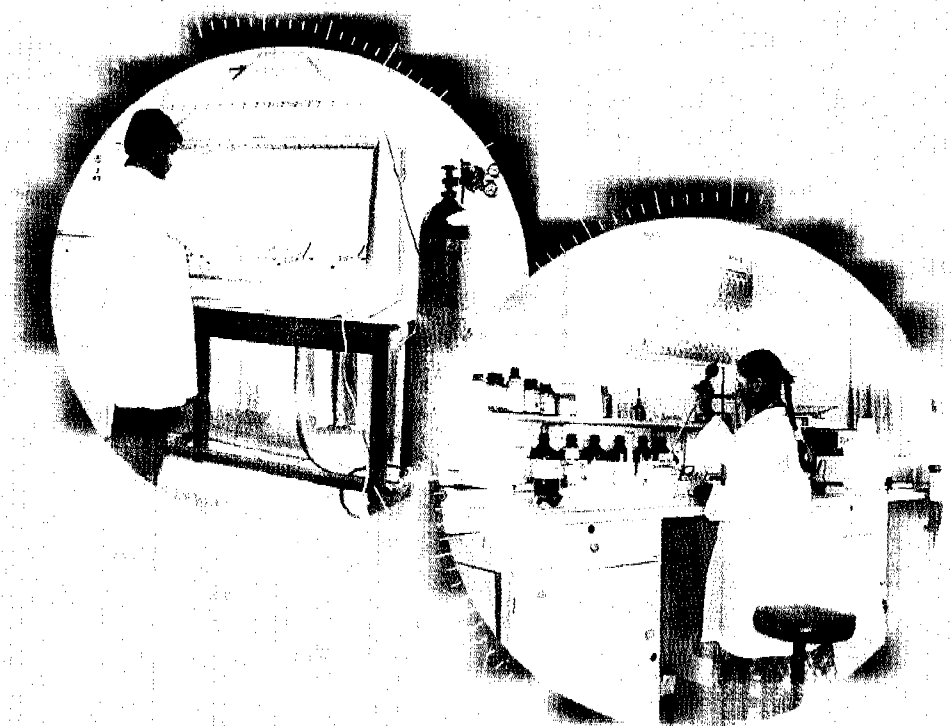

WATSAN PARTNERSHIP PROJECT (WPP)

SWISS AGENCY FOR DEVELOPMENT AND COOPERATION

INTENT